VOLUME 86 NO. IR2
JUNE 1960
PART 1

JOURNAL of the

Irrigation and Drainage Division

PROCEEDINGS OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS

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The index for 1959 was published as ASCE Publication 1960-10 (list price $2.00); indexes for previous years are also available.

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Journal of the

IRRIGATION AND DRAINAGE DIVISION

Proceedings of the American Society of Civil Engineers

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Journal of the
IRRIGATION AND DRAINAGE DIVISION
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IRRIGATION AND DRAINAGE PROBLEMS IN URUGUAY[a]

By J. E. Christiansen,[1] F. ASCE

SYNOPSIS

Uruguay irrigates about 65,000 acres, mostly rice (74%) and sugar cane (15%). Summer rainfall averages about 3.5 in. per month, but frequent droughts seriously affect both crops and livestock. Irrigation can be increased by storage in small reservoirs on tributary streams by means of low earth dams. Some areas will require flood control and drainage before intensive agriculture can be practiced.

INTRODUCTION

During the period from July 1, 1957, to September 15, 1957, the writer visited Uruguay as a consultant for the Food and Agriculture Organization of the United Nations, for the purpose of advising on water resource development for irrigation. The specific purpose of the trip was to review plans for proposed irrigation projects, and to make general recommendations regarding the development of the water resources of the country for irrigation. During a 10-week period, seven field trips were made to various sections of the country to observe conditions and to see the irrigation systems. Since this was during the winter months in Uruguay, none of the irrigation systems were in operation.

Note.—Discussion open until November 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. IR 2, June, 1960.

[a] Presented at the October 1959 ASCE Convention in Washington D. C.

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GENERAL DESCRIPTION

Geography.—Uruguay is located toward the southern part of South America between latitudes 30° and 35° south, corresponding approximately to that of Arizona. It is bounded on the north and northeast by Brazil, on the west by Argentina, with the Rio Uruguay separating the countries, on the southwest by the Rio de la Plata, and on the southeast by the Atlantic Ocean (Fig. 1). The total area is 72,172 sq miles, approximately the size of North Dakota. Although the smallest of the South American countries, Uruguay is larger than the combined area of Denmark, Holland, Belgium, Switzerland, and Albania.

FIG. 1.—URUGUAY

The population of Uruguay, in 1957, was a little more than 2,500,000 according to official estimates. About one third of the people live in the capitol city of Montevideo. Uruguay has the highest density of population of any country in South America and is often considered the most progressive. The people are mostly of Spanish, Italian, and French extraction. There are very few Negroes, Indians, or persons of mixed blood. In both area and population, Uruguay is about the size of the State of Washington.

Topography and Vegetation.—Topographically the country is a continuation of the plateau system of southern Brazil with elevations rising to about 1,000 ft above sea level in the north central part. There are some small mountains in the southeast with a peak rising to nearly 2,000 ft.

Most of the country is an undulating grassy plain, almost treeless except for planted varieties, and some native species that grow along stream channels. There are two varieties of native palms in eastern Uruguay and another in the northwest which are protected by law. In recent years Eucalyptus trees have been extensively planted for shade, windbreaks, and fuel supply. A typical view of the Uruguayan prairie showing a stock-watering pool is shown in Fig. 2.

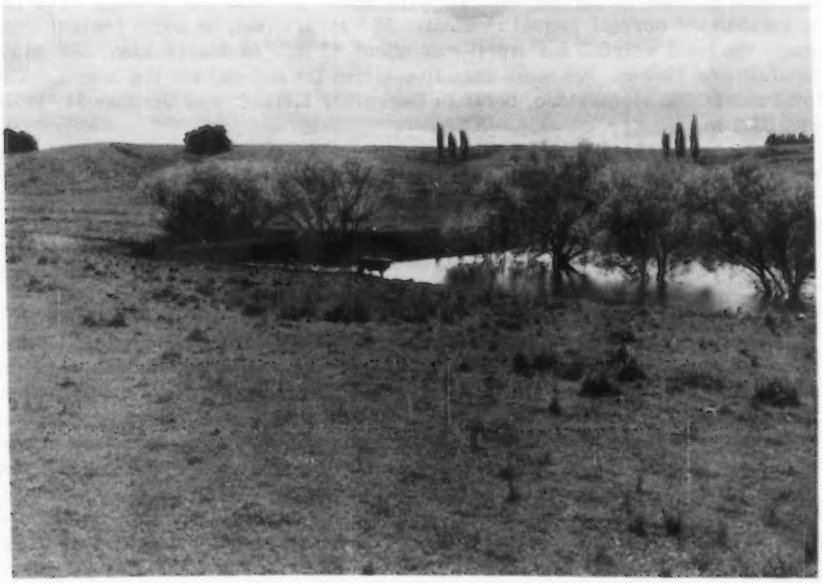

FIG. 2.—STOCK-WATERING POND, PLAINS OF URUGUAY

There is one large low-lying plain in eastern Uruguay, bordering the Laguna Merin, and a narrower coastal plain and lake area along the Atlantic Ocean and Rio de la Plata. The northwest part drains directly into the Rio Uruguay on the west. Most of the central part extending into Brazil on the north drains into the Rio Negro, a tributary of the Rio Uruguay near its mouth. The south and eastern portions drain into the Rio de la Plata, the Atlantic Ocean, or the Laguna Merin. The large low-lying plain in the east, and the southeast coastal plains contain large swampy and marshy areas and are in need of drainage and flood protection.

Climate.—The climate of Uruguay may be described as sub-tropical with extremes of temperature ranging from just below freezing in the winter to above 100 F. inland in the summer. The average annual rainfall for the country is about 42 in., varying from about 37 in. at Montevideo to about 48 in. in the northwest corner. The rainfall is well distributed throughout the year with

an average maximum of about 4.5 in. in March and an average minimum of 2.8 in. in July. At Montevideo the averate monthly rainfall varies from about 2.6 in. in February, July, and October, to 3.8 in. in March and April.

At first it would appear that the rainfall would be adequate for most crops and that irrigation might not be justified. A more detailed study of the rainfall, however, reveals that prolonged droughts are of frequent occurrence, especially in the hot summer months. Summer storms, in general, are of high intensity, with single storms exceeding 5 in. a fairly common occurrence. On occasion, more than 15 in. of rain has fallen in a 30-day period. This results in considerable runoff, and severe soil erosion where the land is cultivated.

Unusually heavy rains and floods occurred during 1959. The rains began on April 8, and during the next 15 days some parts of the country received more than the normal annual rainfall. At Tacuarembo, in north central Uruguay, the total rainfall for April was about 47 in. At Montevideo, the April rainfall was 19.7 in., or more than five times the normal for the month. The total rainfall at Montevideo, between December 1, 1958, and October 31, 1959, was 68.3 in.

The unusual April storms did a tremendous amount of damage, isolating many cities and ranches in the country. The large hydroelectric development on the Rio Negro at Rincon del Bonete was flooded and put out of commission for several months.

IRRIGATION DEVELOPMENT

Agriculture and Livestock.—Livestock production is the principal industry. The 1956 agricultural census[2] showed that nearly 34,000,000 acres were in natural pasture, with less than 5,000,000 acres in agricultural crops. This census listed 7,433,000 cattle, and 23,300,000 sheep. Wool ranks first, and beef second as the principal agricultural products and along with hides, accounts for most of the exports. The principal agricultural crops in 1951 and 1956 are given in Table 1. The extent and growth of irrigation during this 5-yr period is shown in Table 2. Rice is the principal irrigated crop, accounting for 74% of the total irrigated area, and sugar cane is second with 15%.

The irrigated areas are largely in the northwest, near the Rio Uruguay, where both rice and sugar cane are grown, in the eastern zone, where rice predominates, and in the south, where vegetables and fruits are the principal irrigated crops.

Present Irrigation Practices.—Nearly all of the irrigation, at present (1960), is the result of private enterprise, mostly by individuals who pump water directly from perennial streams or lakes and irrigate adjacent lands. Most of the rice growers farm large holdings ranging from several hundred to thousands of acres. Rice growing is highly mechanized. The land is plowed with tractors, levees are constructed with machinery, and the harvesting is done with combines. Since harvesting is done during the season of heaviest rainfall, rice must be artifically dried before being stored or milled. Rice growing, therefore, necessitates a very large investment in an irrigation system, tractors and machinery, and rice driers. Rice can be successfully grown on the same land only 2 yr or 3 yr before yields decline seriously. The common practice is to grow two or three crops of rice, then pasture the land from 3 yr

2 "General Agricultural Census," Ministry of Agriculture and Livestock, 1956. All figures have been converted from metric units and rounded.

to 5 yr before growing the next crop of rice. This, of course, requires the construction of an irrigation system for an area about three times as large as is irrigated each year. One plantation is experimenting with irrigated pastures in rotation with rice.

Sugar cane is grown in rows and irrigated by broad furrows. It can be grown on land that is more rolling than that suitable for rice.

There is a small government-sponsored irrigation project in southeastern Uruguay. Here water is diverted by gravity from a small stream at the mouth

TABLE 1.—AREAS IN PRINCIPAL CROPS

Crops	Thousands of Acres	
	1951	1956
(1)	(2)	(3)
Wheat	1,210	1,950
Forage crops	1,200	1,150
Corn	870	800
Sunflowers	470	450
Other cereals & flax	430	330
Fruit trees & vines	136	136
Vegetables	146	120
Rice	31.3	47.9
Sugar beets	7.8	19.3
Sugar cane	4.4	10.0

TABLE 2.—IRRIGATION DEVELOPMENT, 1951-1956[a]

Crop	Census		Change 1951-56,	Irrigated area in crop, in %		Crop area irrigated, in %	
	1951, acres	1956, acres	acres	1951	1956	1951	1956
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rice	30,300	47,200	16,900	75.9	73.5	100	99
Sugar cane	4,300	9,900	5,600	10.8	15.4	98	99
Vegetables	3,500	4,900	1,400	8.8	7.6	2.4	4.1
Fruit trees	800	900	100	2.0	1.4	-	1.0
Forage	230	680	450	0.6	1.1	0.02	0.06
Vines	170	110	- 60	0.4	0.2	-	0.02
Other	600	510	- 90	1.5	0.8	-	-
Total	39,900	64,200	24,300	100	100	-	-

[a] All figures have been converted from metric units and rounded.

of a canyon and conveyed several miles in an unlined canal to irrigate about 1,100 acres, most of which was in a single holding planted to apples. In spite of a water-charge schedule favoring small holdings, difficulty has been experienced in getting some of the farmers, for whom the water supply was intended, to use the water.

Why Irrigation is Not Extensively Practiced.—Assuming that the consumptive use for summer crops, under climatic conditions prevailing in Uruguay, would be in the range of 5 in. to 8 in. per month, it is apparent that irrigation would be beneficial for many crops now grown, and that it would make possible the production of crops not grown at present. Why, therefore, is irrigation not practiced to a greater extent? There are probably many reasons, some of which are:

1. A water supply is not readily available to most of the land area.
2. The topography of much of the land is such that water could not be easily applied by surface irrigation methods.
3. Most farmers have had no experience with irrigation. Research and extension work is necessary to promote irrigation.
4. The cost of pumping and other irrigation equipment, including sprinkling systems, is relatively high compared with the prices received for agricultural crops.
5. Livestock can be pastured the year around. There has been little incentive to grow crops, such as alfalfa, for winter feeding.
6. The development of irrigation for many crops commonly grown under irrigation in western United States is not warrented because of the relatively small population and present eating habits of the people.
7. Some areas, well suited for irrigation, need drainage and flood protection before they can be developed for intensive agriculture.
8. Transportation of produce has been a limitation in the past, but improved highways and use of modern trucks has opened up larger areas to crop production.

Reliability of Rainfall.—Since the need for irrigation of crops other than rice and sugar cane results from the frequent droughts and uncertainty of rainfall during the summer months, considerable attention was devoted to a study of the rainfall records for selected stations to determine their reliability. Thirteen stations, located roughly on two intersecting diagonal lines crossing the country, were selected for study. Eight of these stations were on a northwest-southeast line, and five on a southwest-northeast line. For each of these stations, the entire period of record was analyzed to determine for the 6 summer months of each year:

a. The mean monthly rainfall.
b. The median monthly rainfall, that is, that occurring 50% of the months of record.
c. The monthly rainfall occurring 5 yr out of every 6 yr, or 83% of the time.
d. The minimum monthly rainfall recorded during the period of record.

The results of this study are summarized briefly in Table 3.

Water Supply.—There are three possible sources of water supply for irrigation. These are:

1. From perennial streams or lakes.
2. From ground water development.
3. From storage of runoff in reservoirs.

All of these sources are being given careful consideration by the government in connection with proposed irrigation developments. In places where water supplies are available from perennial streams, such as the Rio Uruguay,

direct diversion, usually by pumping, offers the most economical solution. The total area that can be irrigated from such sources is limited to areas near sources of supply where pumping lifts are not excessive.

Most of the smaller streams in the country are dry, or nearly so, during the drought periods when irrigation is needed. Any extensive development by diversion from the Rio Negro or its tributaries, except in the lower reaches, would interfere with the present and proposed hydroelectric development, and the question of water rights would have to be resolved.

There is also a question as to the desirability of further development by direct pumping from Laguna Merin, or its tributaries, as the water level in the Lake becomes very low during drought periods, and salt water flows back into the Lake from the Atlantic Ocean. A control of the outlet could remedy this difficulty, but the outlet channel, the Rio Gonzalo, is entirely in Brazil.

Ground water development does not appear promising. An investigation of ground-water supplies has been made by government agencies. Because of the nature of the geologic formation over most of the country, yields from

TABLE 3.—SUMMARY OF RAINFALL DATA

Month (1)	Mean rainfall, in inches (2)	Median percentage of mean (3)	83 Percentile percentage of mean (4)	Minimum percentage of mean (5)
October	3.5	86	46	29
November	2.8	86	47	27
December	3.0	72	33	13
January	3.9	88	37	13
February	3.5	90	47	19
March	5.0	89	51	28
6-month period	21.7	85	43	22

wells are not adequate to make such supplies economical for irrigation. Only in the alluvial areas are yields sufficient to justify ground-water development for irrigation. Excellent wells have been developed in one alluvial area near the Rio Santa Lucia northwest of Montevideo.

Storage of runoff, in relatively small reservoirs on many of the smaller tributary streams, would appear to offer possibilities. There are probably few good sites for large reservoirs, and the construction of adequate spillways to carry the flood flows on the larger streams would be very expensive. It is believed that low earth-fill dams could be constructed on many small streams at a fairly reasonable cost, and that considerable development could result from such a program. One such reservoir has been constructed near Rio Branco, in the northeast, and it is understood that there is another one in the north central part. Detailed investigation of possible dam sites would have to be made to determine the economics of this kind of development.

Stream-flow records are available on very few streams. Records at the hydroelectric power plant at Rincon del Boneta on the Rio Negro in central Uruguay indicate that 38% of the estimated total rainfall on the watershed ran

off. This is probably a higher percentage than could be depended on for a water supply, but because of the nature of the storms and soils, there is considerable runoff which might be stored for irrigation. Research is needed to establish relations between rainfall and runoff from which reliable estimates of available supplies for storage could be made.

Drainage and Flood Protection.--As previously mentioned, some areas otherwise very suitable for irrigation development need drainage and flood protection before they can be used for intensive agriculture. The so-called "Eastern Swamplands" has been under investigation by the government for many years, but financing has not been available for development. This area contains more than 1,500,000 acres of flat land, much of which is flooded during the fall and winter months. The proposed project would reclain about 1,000,000 acres in three stages.

Stage one would include the drainage and flood control canals and levees to prevent flooding of the area, and to convey the flood waters to the Laguna Merin.

Stage two would consist of four reservoirs, one on each of the principal rivers flowing into the area.

Stage three would consist of the construction of a hydroelectric plant at the major dam, and the irrigation works to serve the area. The total cost, as estimated in 1955, was the equivalent of about $25,000,000.

A much smaller, but somewhat similar, area in the southwest was being reclaimed by an individual who was planting the area to trees for the development of a pulpwood industry. At the time of the visit, about 4,000 acres had been drained and planted. It appeared that with flood protection, drainage, and irrigation the soils would be suitable for many agricultural crops.

The heavy storms and floods of April, 1959, amply demonstrate the need for flood protection in connection with irrigation and drainage developments. Severe flood damage occurred in many parts of the country that were not normally subject to flooding.

CONCLUSIONS

Some of the conclusions arrived at as a result of the studies were:

1. Irrigation would be beneficial for most summer crops and, also, for pastures.
2. Research should be conducted to determine the economic aspects of irrigation agriculture.
3. Basic policies that would provide a guide for the future development of the water resources of the country should be formulated.
4. Although the present development has been carried out mostly by individuals, future developments will depend more and more on government sponsorship.
5. Meteorological records are quite adequate, and the present topographical survey is progressing satisfactorily, but little has been done to provide stream flow data essential to the planning of irrigation projects.
6. Financing the proposed projects is a major obstacle to development.

ACKNOWLEDGEMENTS

While in Uruguay the writer worked in close cooperation with the Instituto Nacional de Colonizacion, and is especially indebted to Ingeniero Engenio Topolanski, with whom he was associated.

Journal of the
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

HERITAGE OF IRRIGATION IN IRAQ

M. R. Lewis,[1] M. ASCE

SYNOPSIS

The history of irrigation in Iraq for 6,000 yr and its influence on the thinking and customs of the people are reviewed. War, floods, excess salts, sedimentation, and changing trade routes are discussed as causes of the decline or abandonment of great irrigation systems. It is concluded that irrigation is the essential heritage of Iraq.

INTRODUCTION

In considering the history of irrigation in Iraq, it is necessary to go far back into prehistory before the development of writing by the Sumerians. The archaeologist in attempting to reconstruct the life at a primitive village must depend on the relics of human habitation which he finds, generally, by the excavation of the fill in caves or of mounds covering debris of village after village resting on ancient settlements. These may consist only of the ashes of paleolithic man's campfire and the bones of his quarry together with stone or bone implements and, perhaps, his own bones. Studying a site occupied near the end of prehistory, he may find the foundations of elaborately planned buildings and temples together with many stone or clay artifacts. Such things as stone hoes and sickles made of bone, stone, and hard baked clays, and sometimes with flint blades set with bitumen, give good indications of the status of agriculture at the time the site was occupied. In some excavations of very early settlements

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[1] Assoc., Carroll E. Bradberry and Assocs., Los Altos, Calif.

traces of ditches and mud banks can be identified as irrigation or drainage channels.

Writing developed slowly from simple pictographs and numbers represented by dots or punched holes, and about 3000 B. C. the cuneiform system was developed by the Sumerians and written history began. Surprisingly complete historical records have been discovered. For instance, Sir Henry Layard, in 1850, and one of his assistants, 3 yr later, found 25,000 inscribed clay tablets representing two almost complete royal libraries in the ruins of Nineveh, near Mosul.

In addition to these sources, there are the numerous stone inscriptions on monuments, buildings, and rock outcroppings; the remains of ancient irrigation works; and the records of travelers and of formal historians. So there is a wealth of material on which to base a history of irrigation in the area and to consider its impact on modern Iraq.

EARLY SETTLEMENT

The present country of Iraq dates back only to the agreements ending World War I, but Mesopotamia (The Land Between the Rivers), which covers essentially the same area, has been a geographic and more or less historic entity for more than 5,000 yr. How much more, no one knows. Radiocarbon dating of land-snail shells recovered from the site of one of the earliest known villages of farmers, Jarmo, at the edge of the foothills east of Kirkuk in northeast Iraq, is reported as showing occupation by man in 4758 B. C. plus or minus 320 yr. Coon reports that in Belt Cave in northern Iran he found evidence of the domestication of plants and animals some 2,000 yr earlier.

For many years it has been thought that at the time of the first settlers in Iraq, the Persian Gulf extended much further north than it does at present and covered a very large part of the present delta area. According to that theory the earliest settlers gradually followed the formation of the delta and, thus, worked down to the location of the earliest cities. On archeological evidence it appears that the earliest habitations so far discovered in extreme southern Iraq are 1,000 yr later than that at Jarmo. Recently, however, geologists have seriously questioned the theory that in recent geological time the Gulf extended much, if any, further north than it does today. The more recent opinion is that the whole delta area is gradually sinking at a rate more or less equal to the rate at which the sediments brought in by the three rivers, the Euphrates, the Tigris, and the Karun, flowing from Persia, have built up the land surface. These who hold the latter opinion believe that there may well be remains of villages as old as Jarmo still buried beneath the delta lands, even below the present marshes.

It is, generally, believed that the earliest settlements in the Middle East are to be found in an arc running from the northern tip of Egypt up along the eastern Mediterranean coast to and across northern Syria and Iraq and, thence, southeast along the western slope of the Sagros Mountains on the border of Iran. This strip is known as the Fertile Crescent. In this area growing of cereals and keeping goats, sheep, cattle, and hogs can be carried on without irrigation. People who had achieved a village culture based on agriculture in this area gradually spread southward and eventually came to the semiarid section where crops could be grown only during favorable years and finally to the true desert where no crops grow without irrigation.

Limited areas are irrigated in northern Iraq but the principal impact of irrigation on the culture and economy of the country occurs in the flat lands, below the foothills to the north and east and the higher desert to the west. The two sections were for many years separately governed and became known as Assyria to the north and Babylonia to the south. The climate of Babylonia is classified as hot, desert, and can best be characterized by the temperature and precipitation records at Baghdad, in the northern part of the section, and at Basra, in the southern (Table 1).

TABLE 1.—MONTHLY AND ANNUAL MEAN TEMPERATURE AND PRECIPITATION AT BAGHDAD AND BASRA, IRAQ, FOR THE PERIOD 1938 TO 1957

Month	Baghdad		Basra	
	Temperature, °F	Precipitation, inches	Temperature, °F	Precipitation, inches
(1)	(2)	(3)	(4)	(5)
Jan	49.8	.92	54.9	1.07
Feb	55.2	1.14	58.6	.78
Mar	59.7	1.13	65.1	1.04
Apr	70.9	.53	75.0	.92
May	82.0	.13	85.8	.26
Jun	89.4	.04	90.9	tr
Jul	93.5	tr	93.2	.01
Aug	93.2	tr	92.7	.tr
Sep	86.7	.04	87.5	tr
Oct	76.6	.12	79.1	.03
Nov	63.7	.75	68.2	1.15
Dec	52.5	1.10	57.4	1.38
Total	72.5	5.90	75.5	6.64

BEGINNINGS OF IRRIGATION

In the beginning, irrigation was a very primitive affair. Probably, some observant individual noted that a few wheat or barley grains dropped by accident near a water hole or beside the water jar, grew and, if not found and eaten by some animal, produced seed. From that observation seed was planted and watered by hand. One year the seed was planted near a stream and the villagers found it possible and simpler to dig a ditch from the stream than to carry water. In Iraq, in contrast to conditions in Egypt, large areas were not flooded each year and then naturally drained and conditioned for planting and crop production from the water stored in the soil.

On the streams or ponds in the delta area, the problem of getting the water into the ditch would be difficult and must have required lifting it, at least 1 ft or 2 ft. At first, this was probably done by splashing it up with a flat stone or piece of bark just as an inexperienced irrigator today uses his shovel to wet the surface of the high spot he cannot quite induce the water to flow over. Later simple baskets made of reeds or skins were used; when these were fitted with thongs, two men could lift quite a respectable stream. As the lifts got higher and ingenuity greater the shaduf was invented. This is a long counter-weighted lever with a basket or sack on the long end. These or similar devices were the machines the god Ningursu was expected to look after in early times. Sometimes this lifting of water took place at the head of the ditch, at other times from the ditch onto the cropped land, or possibly at both places.

As the villages grew and more and more food and pasture was needed, larger and longer ditches were required. Somewhere along the line it was discovered that water could be diverted from the river and carried in a ditch to lower land where it could be brought out on the surface by gravity flow alone. Two topographic features of the area greatly favored this development. The rivers have developed broad ridges on which they flow, with lower basins on one or both sides. In the area between, ancient canals led from the Euphrates, irrigated large areas, and tailed into the Tigris. To the east of the Tigris, canals were more like those common in the western United States in that they diverted from the river, irrigated an area between the river and the foothills, and finally wasted back into the river.

In the delta area, drainage canals cannot easily be carried down the valley comparatively short distances and discharged back into the river. The comparative ease of diverting large quantities of water, the lack of drainage, the lack of measuring devices, and inadequate control of water distribution resulted in raising the water table and the accumulation of excess salts on and near the surface of large areas of land. The fact that a tremendous area of land was available for shifting cultivation from tract to tract and the comparative ease with which the salts were leached out of the surface soils either by natural or artificial means has made possible the continuous large scale irrigation over 4,000 yr or 5,000 yr.

CITY-STATES

Even without the archeological evidence of prehistoric stone tools, such as hoes and sickles and the written records beginning about 3,000 B. C., it would be obvious, from the ruins of large cities with immense public buildings in a desert area such as southern Iraq, that large scale irrigation had long been established. In historic times the great irrigation systems are described in more or less detail and traces of many can be found for miles. Even more interesting is the fact that some of the canals still exist in usable form. For example, Entemena, governor of Lagash, dug a new boundary canal to supply his lands and put an end to frequent quarrels, sometimes leading to war, between Lagash and Umma. This canal, built about the middle of the third millenium B. C., is still in use under the name of the Shatt-al-Hai.

The city-states which had developed to this time were continually warring with each other, often over water. First one and then another would get the upper hand and rule a number of others. This amazing development from simple villages to the great city-states, sometimes grouped together under a single government together with extensive and intricate networks of irrigation channels, was the work of the Sumerians, whose origins are still clothed in mystery. Somewhat later a Semitic tribe, the Akkadians, settled to the north of the Sumerians.

BABYLON

About 2,200 B. C. another Semitic people from the west, the Amorites, who had been spreading out from a small upriver town, conquered the area and made their city, Babylon, the capital of a huge empire. The most important ruler of Babylon during the period was Hammurabi whose reign is commemorated on a stone cylinder now in the Louvre, in Paris. In this account, the king says that

when the gods gave him the lands of Sumer and Akkad to govern he dug the the canal, Hammurabi-the-Abundance-of-the-People, to irrigate the land and make peaceful dwellings for the people. The records of the next 1,500 yr do not show any great events in the irrigation history of the country.

In 691 B. C., Sennacherib, king of Assyria, razed Babylon and diverted a large irrigation canal to wash over the ruins. In the meantime, the Chaldeans had been pushing north from the area of the Persian Gulf for 400 yr and in 606 B. C. occupied the site of Babylon. Their leader, Nebuchadnezzar, rebuilt the city adding a royal palace with its roof covered by the Hanging Gardens, deemed by the Greeks one of the Seven Wonders of the World.

Cyrus, the Persian, was the next conqueror of Babylon. He is reported to have succeeded in entering the city by first diverting the Tigris, which flowed under the walls, either by a bypass canal or by breaching the levees some distance upstream. Again, Alexander the Great took Babylon and died there after his invasion of India, in 323 B. C.

During the next 500 yr, Babylon was conquered by various groups—Parthians, Greeks, and Romans. Trajan, the Roman emporer, visited Babylon and found it in ruins. Still again, the Parthians occupied Babylonia and were in turn defeated by another Persian group, the Sassanians. The latter built the great arc Ctesiphon which stands to this day, the greatest unreinforced brick arc in existence. They held the country for 400 yr and during that time rehabilitated the irrigation systems. It is believed that most of the abandoned canals, seen all over the country, were in use during this era.

ARAB CONQUEST

Near the end of the Sassanian period, a series of great floods did terrific damage to the irrigation works. In an attempt to stop one break, King Chosroes sacrificed 40 dike-men in vain. A few years later, his successor, the last of the Sassanian kings, Yezdigird III, had 400 engineers and their associates executed in his anger at their failure to prevent or stop the breaks in the dikes. Sir William Willcocks believed that the disruption caused by the floods, and even more by the loss of so many of the most experienced hydraulic engineers in the country, was a major factor in the easy defeat of the Sassanians by the Arab Mohammadans.

During the first century of Arab control there was little to report of irrigation. The Abbasid Caliphate which followed built Baghdad into the magnificent capital of Harun-al-Rashid of the "Thousand and one Nights" stories. They also did much to improve the irrigation projects and get them back into working order. After another interim of 500 yr, in 1258 A. D., Hulagu Khan and his Mongols sacked Baghdad and the irrigation systems fell into decay. They were followed in 1533 A. D., by the Ottoman Turks who were no better and the country experienced a dark age of 600 yr. Beginning with Midhat Pasha, just under a century ago, a gradual redevelopment has been accomplished in Iraq.

IRRIGATION AND THE LIFE OF THE PEOPLE

With this brief summary of the history of irrigation in Iraq as background, the place of irrigation in the culture of the area will be indicated with an attempt to answer the oft-repeated question, "What caused the downfall of the great irrigation projects of the past?"

In communities in the United States, such as the Salt River Valley, Arizona, or the San Joaquin Valley, California, where cultivated crops are absolutely dependent on irrigation, the water supply is a perennial topic of conversation, newspaper comment, radio and television newscasts, law making and litigation, prayers, and even, in case of severe drought or flood, of special religious services. In the ancient cities of Mesopotamia irrigation was literally a life and death matter for people, both individually and as sovereign states. Inevitably, its influences penetrated all phases of life both rural and urban.

RELIGION

In Babylonian theology one of the most important gods was Ea, sometimes called Enki. He was God of the Waters in earlier Sumerian times and is represented by innumerable carvings recovered from the ruins of the early cities and temples. Many of the cylinder seals show Ea holding a vase from which spout two streams of water, these representing the Twin Rivers. Fish are often shown swimming up the streams. In addition to Ea, there were other principal gods, among them Ningursu, who was responsible for the irrigation machines. Each stream, river, or canal had its own particular deity in the early pantheon.

The priests were also rulers and the temples housed the administrative forces of the community, in addition to their purely religious functions. In this combined capacity these were the chief buildings in each city. In many cases, they were surrounded by storehouses in which were kept the gifts to the gods and the crops, and other goods collected as taxes in kind. Huge surpluses of grain were, thus, accumulated. These insured the survival of the people in case of disaster. They also served as a great temptations for raids by other cities, nomad tribes, and foreign people.

All this is well recorded for the territory of Lagash where the temple accounts of Bau have been recovered almost completely. Bau was the chief god of the city and owned 7 sq miles of irrigated farm land. Three-fourths of the area was assigned as family plots. The balance was farmed for her personal account by wage-earning tenants who paid one-seventh or one-eighth of their produce as rent or by part-time labor of the remaining clansmen. In her temple worked 21 bakers, helped by 27 female slaves, and 25 brewers with 6 slaves. Forty women prepared the wool of the temple flocks for spinning and weaving by other women or girls. The smiths and other artisans, officials, clerks, and priests were men. The temple owned and supplied its workers with such items as metal hoes, plows, plow-animals, wagons and boats. Bau owned breeding stock including a stud bull from Elam. It was necessary to bring in outside blood to keep the cattle from deteriorating in the hot damp plains.

This system of divine households insured the utilization of the land, maintenance of essential irrigation canals and the production of the great surplus of grain required for the non-farming community and for trade with other areas.

LAW

As is true in arid countries today, many laws and, unfortunately, much litigation was devoted to water rights and water management in ancient Babylonia. The very early records contain fragmentary laws and several codifications. One of the more complete was proclaimed by Ur-engur and his son Dungi, kings

of Ur. Probably the best known and certainly the most quoted code is that of Hammurabi, heretofore mentioned as an early king of Babylon. Two of the laws read as follows:

> If anyone be too lazy to keep his dam in order, and does not so keep it; if the dam break and all the fields be flooded, then shall he in whose dam the break occurred be sold for money, and the money shall replace the corn which he has caused to be ruined.
>
> If anyone open his ditches to water his crop, but is careless, and the water flood the field of his neighbor, then he shall pay his neighbor corn for his loss.
>
> There are many other sections dealing with water and canals, as well as with all phases of community life. It is evident that the rulers were very much concerned with the use of water and attempted to insure economy in that use and to prevent damage by flooding and, probably, water-logging of cropped land.

COMMERCE

There were important interrelations between commerce and irrigation. The trade routes were in part fixed by the local availability of food for men and feed for animals and, in turn, the market, thus created, encouraged the expansion of agriculture which necessarily meant an increase in irrigation. Thus, the meeting and crossing points of major overland caravan routes became great cities with extensive irrigation projects surrounding them.

Southern Iraq had no mineral resources beyond its soil, little, if any, timber, and, because of its aridity, little native vegetation or wild animal life. True, the desert did and still does provide pasturage for the goats and, especially, the camels of the nomads, but never enough to support settled villages. Where these do exist in the deserts, they are in oases dependent on springs or other permanent water supplies. Even stone, for the simple stone-age tools, knives, axes, sickles, etc., had to be brought from afar. In early times, these must have been secured by exchange for the products of the irrigated fields. The early records on clay tablets, found in such abundance, cover an extensive commerce of this kind.

The social organization in prehistoric times can be conjectured only from archeological findings and comparison with primitive people of today. It is certain, however, that long before the earliest cities came into being, primitive man had organized groups for hunting, fighting, religion, and other purposes. It is not difficult, then, to imagine that they could manage the cooperation necessary to operate small community ditches. In the earliest written history the priest-kings had control of the irrigation canals. It appears that the absolute necessity of team-work in their operations was a powerful stimulus toward urban life. The difficulty of establishing a new settlement would give the group-chiefs much greater control over the young people, since when the latter became dissatisfied, they could not simply walk out and set up huts of their own somewhere else. Also, the rulers of the larger cities who had control of the irrigation works could coerce the cultivators by withholding water from recalcitrant groups or individuals. Still another influence for permanency of settlements was the ubiquitous date palm. All parts of the tree were useful; the fruit

and hearts for food and wine; the leaves for thatch, woven mats, and baskets: the trunks for roof timbers and posts; and the kernels for fire, if for nothing else.

CAUSES OF DECLINE

Many explanations for the decline and abandoment of canals and whole irrigation systems have been given, but the question has not yet been satisfactorily answered. There has been a tendency for each writer, whether a student or not, to ascribe a single cause as outstanding. Each of the following conditions has been held responsible at one time or another: war, flood, erosion, water-logging, alkali, sediment, neglect, climatic changes, and changes in the trade routes. It seems probable that many of these were causative factors; more often than not, several at the same time.

WAR

Even a cursory reading of history shows that over the millenia, war and its results have been frequent and far-reaching destroyers of irrigation works and of their owners and operators. Cutting off the enemies' water supply has everywhere and from time immemorial been a standard procedure in siege operations. In Iraq, the canals were themselves a part of the defense works of many cities. Therefore, almost all attackers, whether neighboring cities or foreign empire-builders, of whom there were many, made their first aim the more or less complete destruction of the water supply and irrigation works. The philosophy of many of the conquerors of antiquity required that the enemy should be completely and permanently annihilated. Obviously, one of the best ways to achieve this was to completely destroy food production in the area. In babylonia this was most simply accomplished by completely wrecking the headworks and canals.

A few instances of wide-spread destruction in the course of wars are cited:

Ur and most of Sumer were conquered by Guti tribesmen from the north in about 2000 B. C., with resultant destruction, either by direct action or by neglect, of the elaborate irrigation networks built up during the preceeding millenium.

The razing of Babylon in 691 B. C., by the Assyrian, Sennacherib, has already been mentioned.

Ashurbanipal, of Assyria, in 639 B. C., boasted, "For a distance of one month and 25 days (march) I devastated the districts of Elam. I spread salt and thorn bushes therein. . . . its fields I left for the asses, the gazelles, and all manner of wild beasts to people."

During the century before the fall of Nineveh, about 612 B. C., Babylon and its tributary cities were almost completely destroyed in repeated captures and recaptures and the surrounding districts were uncultivated for many years. The canals became choked with sediment and wind-blown sand, and water, out of control, flooded lands long since reclaimed from swamp.

The Mongol, Hulagu, in the 13th century A. D., sacked and razed Baghdad. He thoroughly destroyed the dikes and headworks of the irrigation systems which at the close of the 12th century had controlled and diverted the waters of the two great rivers into a "million" irrigation channels.

Tamerlane repeated Hulagu's depradations some 150 yr later. For 300 yr after the Mongol arrival, Iraq was a shabby and impoverished outpost of the Ottoman Empire whose capital was Constantinople. Not only was the ruination of the irrigation works disastrous, but the small number of survivors and the general unrest prevented rehabilitation or even proper maintenance of what was left. The uncontrolled waters added to the distress. Lack of government control permitted the landowners to breach canal banks in order to obtain illegal water, thus, adding to the chaos.

FLOODS

Floods were a frequent cause of disaster. The Sumerians had a flood story almost identical with that of the Bible. Similar legends are known in Greece, India, Ireland, Egypt, Mexico, and California.

The ancient records and the accounts of early historians break their chronicles at the time of a great flood, recounting legendary doings of gods and kings prior to that time and reporting historical events thereafter. Certainly, in Iraq, a flood can be envisaged which could have disrupted the whole life of the dwellers in the great irrigated valley with its numerous cities and villages.

In addition to the archeological evidence of many great floods in prehistoric times, the ancient records include accounts of many catastrophies to irrigation works of varying magnitude brought about by floods. Floods created the destruction or neglect of canal and river levees and irrigation headworks, as well as those due to natural causes, resulted in the abandonment, either temporary or permanent, of many canals over the long history of the country.

Ancient rulers, as some modern ones, failed to recognize that no engineering works can provide perfect and complete protection against all possible floods. The great floods of the 7th century A. D., have already been alluded to. Willcocks, after an intensive study of the remains of ancient canals, reported that in a number of instances rivers in flood had washed out the headworks and shifted their flow to the canal which then became so degraded as to be more or less useless; or the banks were broken and the water escaped into the marshes.

SALT ACCUMULATION

The statement of Ashurbanipal that he had spread salt over the land is one of the few known references, in the ancient records, of excess salts on the land. On the other hand, the great emphasis in laws and accounts on the dangers of flooding by improperly controlled water seems to infer realization that more or less permanent damage resulted to the land from water-logging. In an arid delta like southern Iraq, damage by soil erosion tends to be local and temporary. Gradients are not great enough, the cause deep gullying, and there is little difference between top soil and subsoil. Thus, the danger from mismanagement of water is more apt to be indirect because of water-logging and the consequent rise of an excess of dissolved salts. There is no question that much land in southern Iraq is out of production because of high water-tables and salt accumulation. It is, however, doubtful that over many years this problem has been as serious as some writers have claimed. This is not to say that drainage has not always been and continues to be one of the paramount problems of the area.

SEDIMENTATION

Over the millenia sedimentation has been extremely troublesome to the irrigation canal operators, while at the same time being an all-important sourse of fertility. Evidence of the difficulties it has created is easily found in the field and in the records. The most striking evidence is the sight of whole series of ancient canal banks running side by side across the landscape. These do not represent a series of competing canals in use at the same time such as can be found on a small scale in many western valleys in North America. In Iraq, they are simply the multiple spoil banks of a former canal built up over the years by the sediment cleaned out of the bed periodically, sediment carried up in great part on the heads of women, or perhaps in baskets with double handles at both ends and carried by two persons. In either case, the banks eventually became so high that it was easier to build a new canal than to continue to clean out the old one. This is a problem which is apt to get more and more troublesome as the river waters are more completely used.

The records are full of the ruler's claims that they dug this or that canal for the glory of Ningursu and the well-being of their people. Also, the filling up of the canals as a result of purposeful or careless neglect of maintenance is repeatedly reported.

TRADE ROUTES

Irrigation and trade routes have always been to some extent interdependent. For instance, as the sea route from India up the Red Sea and, thence, through the ancient Pharoah's canal to the Nile, was opened or closed, the great commercial cities of Iraq and their surrounding irrigated areas on the overland routes waned or waxed. The availability of food and fodder, on the great irrigated areas, to the commercial caravans was a strong inducement toward the development of the trade routes through the irrigated valleys.

CONCLUSIONS

Iraq, as an historical entity, and irrigation appeared together some 6,000 yr ago in Mesopotamia, in the valley of the Twin Rivers. Ever since they have risen and declined together. Perhaps nowhere else in the world has civilization been so closely tied to man's control of water. Except for the newcomer, petroleum, irrigation agriculture has been almost the sole support of Iraq, first, as the direct source of subsistence, and second, as the source of trade-goods and exports. The emphasis devoted to irrigation and drainage by the Iraqi Development Board in recent years indicates the realization by the government that its well being and that of the people is unequivocally dependent on irrigated agriculture. Indeed, throughout history, the essential heritage of the people of Iraq is and has been irrigation. It is to be hoped that neither inside or outside subversive influences will overshadow its importance.

ACKNOWLEDGEMENTS

The author acknowledges with sincere thanks the essential help of his wife, Mary G. Lewis, who conducted the historical research for this paper.

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Journal of the
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

DRAINAGE AND WATER MANAGEMENT RESEARCH IN WESTERN EUROPE[a]

By William W. Donnan[1], F. ASCE

SYNOPSIS

This paper attempts to indicate to the reader the ease with which an American visitor can communicate with the engineers of western Europe. The author presents a description of the research facilities visited and the names and works of the engineers with whom he conversed and exchanged ideas. In addition, a brief description is presented of the vast number of institutions engaged in this type of research in the Netherlands.

INTRODUCTION

In the late summer of 1958 the author was privileged to make a 3-week study tour of drainage and water management research in Great Britain, Denmark, and the Netherlands. The report of this study tour is written with two objectives in mind, namely: 1) To describe the ideas, tools and techniques of the European engineers and technicians; and 2) To interest the reader enough so that he will inaugurate correspondence and exchange of ideas and information between countries. Toward this end there is listed, under Acknowledgments,

Note.—Discussion open until November 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. IR 2, June, 1960.

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a number of names and addresses of individuals who would be valuable first contacts to anyone wishing information on drainage and water management research in the three countries the author visited.

It should be emphasized that contacts with engineers and scientists outside the United States is not difficult. In western Europe the language barrier does not exist. Anyone who is interested in securing more details of the work herein described will find that these contacts are worthwhile and rewarding.

GREAT BRITAIN

The visit to Great Britain centered mainly on the School of Agriculture, University of Cambridge, Cambridge, England. The drainage and soil physics work carried on here is under the direction of E. C. Childs.

Of considerable interest to anyone working in drainage is the famous tank which Childs built in cooperation with the Agricultural Research Council of Great Britain. This tank, estimated to be 50 ft by 50 ft square and 8 ft deep, is used for a variety of experiments on tile drainage, falling water tables and nonsteady flow phenomenon. A feature of this tank experiment is the water application system developed to apply water by means of sprinklers at an infinite variety of volumes. Child's group has developed one device which, it seems, could be incorporated into any of the tanks or laboratory devices where the objective is to determine the free water surface. It is a device for recording pressure distributions in porous media during fluid flow experiments.[2]

Working with Childs on specific problems of research is A. N. Ede, Agricultural Engineer. Ede has done a lot of work developing a machine to lay continuous concrete tile lines behind a mole device, and has published a number of papers on this work.

Recently Ede has been working on field measurements of rainfall, water levels, and tile flow phenomenon in hopes of securing a large backlog of field data. These data along with empirical equations are to be used in developing theories on the nonsteady state conditions of tile drainage. During the conduct of these field measurements of water table and tile flow, Ede and Childs have developed 1) a simple, economical observation well with float recorder and clock in a single unit; and 2) a tile flow recorder which employs the principle of heat transfer, thermistors, and calibrated flow charts for obtaining instantaneous flow measurements.

Childs and Ede have approximately 8 or 10 individual fields where they hope to be able to record rainfall, water level fluctuations, and tile flow. Two interesting field trips were made to the Fenlands Drainage District. These lands were essentially marsh areas until 1880 or thereabouts when the government began extensive drainage works. The drainage system has gradually been improved. At the present time most of the main natural drainage ways, rivers, and streams have been diked up with levee works to entrain their flows to the ocean. Tidal gates and other large control structures have been built. The former marshland areas have been reclaimed with tile drains and are cropped to pasture, grain and forage.

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DENMARK

Denmark has an area of 16,575 sq miles and consists of about 500 islands and the mainland area of Jutland. The country is characterized by an extremely flat topography. One of the highest points in the entire country is Himmelbjerg (Hill) on Jutland, which has an elevation of 565 ft above sea level.

90% of the land area is productive, and nearly 65% is cropped, the balance being in reforestation areas. While one hears quite a lot about the reclamation work of the Netherlands, there is also a great deal of tidal and heath land reclamation work accomplished, and in process in Denmark. Several hundred thousand acres of tidal lands have been reclaimed by building large sea wall dikes to straighten out the coastline and then by draining the newly created, shallow, land-locked areas.

This development work and the work on the heath lands reclamation is carried on by the Danish Heath Society with headquarters at Viborg, Jutland. This agency carries on an intensive program of hydrological measurements somewhat akin to the United States Geological Survey, and it also supervises the drainage engineering program.

Tile drainage in Denmark started in 1850, and today 40% of the arable land is tile drained. The depth of drains ranges from 80 cm to 120 cm. Spacing is predicated upon experience. The soils are extremely heterogeneous. Spacings range from 14 m to 18 m in sand to sandy loam soils. They are usually 10 m in clay soil. Early tile drains were 1 in. in diameter (inside). Today most tiles are 2 in. inside diameter. The trend is toward using 3-in. diameter tiles in the future.

Drainage is more or less subsidized by the Danish government. The large drainage systems, dikes, and pump works are all done by the government. Money is appropriated for these works and they are called reclamation programs. The individual farm drainage systems and tile systems on fields are planned and designed by private engineers. These plans are submitted for review; if approved, the government pays 50% of the total cost. The balance is also paid by the government but is collected from the land owner over a 10-yr period. Tile drainage costs are approximately 2,000 kroner per hectare (800 kroner per acre or $115 per acre). Tile drains are installed by private contractors during the period from September to December. Much of the tiling is still done by hand digging.

Anyone working on the problems of water balance in the soil would profit from contact with H. C. Aysling at the Hydrotechnic Institute, Royal Veterinary College, Copenhagen, Denmark. He is doing some exceptionally interesting work with lysimeters. Aysling has two sets of three lysimeters 2 m-by-2 m square, and made of concrete. These lysimeters are 80 cm deep and their sharp upper lip is 5 cm below ground surface. They have been packed with 15 cm of gravel sand and then filled to ground surface. Water level is held at 45 cm. One set of lysimeters is irrigated; the other set is not irrigated. They are located on a plot of close-cropped grass turf 350 ft square in an agricultural area. At the same location various climatic data are being gathered—wind, rainfall, evaporation, humidity, temperature, radiation, and back radiation. The evaporation pan used is a copy of the Young screen pan. According to Aysling, this pan has proved to be the "integrator" of all those factors which influence the use of moisture by the turf. In fact, since 1957, Aysling has used the pan as his reference for irrigation needs. Whenever the pan needs to be

replenished, the irrigated plots are irrigated. The irrigated plots use 10% more water than the nonirrigated plots. All water controls and all automatic measurements are handled from a control bunker built along the south edge of the plot. They are assembling a tremendous amount of data, which is recorded automatically on charts.

Aysling also has tensiometers installed in some plots at depths of 25, 50, 75, 100, 125, and 150 cm. These are of the old type. He has found that roughly half of the available water in the root zone can be used before appreciable reduction in consumptive use and production takes place. This is a moving value for any one crop since as the roots go deeper, the amount of water available becomes greater.

Perhaps the most surprising single revelation of the visit to Denmark was the extreme interest of the Danish people in their water resources. Here is an area which would be classed as essentially humid. Yet everyone seems to be talking about and interested in the most economical use of their water supplies.

There is an obvious conflict of interests, the same as in our arid western United States. Metropolitan Copenhagen is short of water and has drawn down the underground well supply to a point where sea water is intruding in some areas. They would like to create fresh water lakes, and their interests conflict with agrarian groups who would like to drain areas to provide more land. These problems are being worked out gradually through the application of engineering and economics.

NETHERLANDS

The Netherlands is even smaller than Denmark, having only 12,504 sq miles of area. This is about half again as large as Massachusetts but contains over 820 people per sq mile. About half of the area is below sea level. The famous Dutch dikes, sea walls and drainage systems are a requisite to use of much of the land.

The Netherlands is truly a mecca for the drainage engineer, and the main center of activity is at the Agricultural University, Wageningen. This town of about 10,000 to 15,000 is the focal point for a vast complex of institutes and departments dealing with agriculture. Its claim to being the center of agricultural science is well founded.

The following is a partial list of some of the institutes dealing specifically with soil and water management problems. There are perhaps 20 to 30 others dealing with crops, forestry, veterinary medicine, and agricultural industry: 1) State Agricultural University—Department of Land Drainage and Land Improvement; 2) Soil Survey Institute (Bennekom); 3) Laboratory of Soil and Crop Testing (Oosterbeck); 4) Institute for Land and Water Management Research; and 5) International Institute for Land Reclamation and Improvement. In addition, these institutes are closely allied with the previous five listed: 6) Government Service for Land and Water Use (Utrecht) [Comparable to the American Soil Conservation Service, Dept of Agriculture (SCS)]; and 7) Research Department of the Zuiderzee Reclamation Project (Kampen).

Agricultural University Department of Land Drainage and Land Improvement.—Anyone planning to visit the Netherlands to observe their drainage, and soil and water management programs should write to F. Hellinga, at the address indicated in the Acknowledgments.

Hellinga is also Secretary of the Academic Senate. Almost all of the Dutch scientists speak English, thus making it easy to exchange information and ideas. Hellinga's department offers undergraduate and graduate courses in drainage, reclaiming of lands, and relocation. A. J. Zuur also gives graduate courses in reclamation although Zuur's office is in Kampen. D. A. Kraijenhoff van de Leur, a research engineer working with Hellinga, is doing some very interesting theoretical work on hydrology and the falling water table phenomenon.

Soil Survey Institute (Bennekom).—This institute is located at Bennekom, about 2 miles from Wageningen. The director of this institute is F. W. G. Pijls. Pijls has visited the United States.

This group does all the soil mapping and soil classification. They seem to be doing a fine job of soil mapping and are trying to make their mapping more adaptable to the physical planning for engineering design, so that they can be used, for instance, for drainage design purposes. One of the most interesting functions of this institute from a drainage standpoint is their measurements of soil samples. They test for pore space and compile pf curves that are then utilized by the drainage engineer for design purposes. They are also doing pedological research and preparing an overall soils map of the Netherlands on a scale of 1 to 50,000.

Laboratory of Soil and Crop Testing (Oosterbeck).—The director of this laboratory is F. J. A. Dechering.

All the tests on soils and crops are done here on an assembly line basis. They have developed "cook book" methods and also have introduced statistical analysis of the validity of their tests and have created an extremely efficient testing laboratory having a high standard. This laboratory is mentioned because it is felt that such facilities should be considered for our own soil and water research program on a regional basis. In the United States techniques, tools and methods have been developed which, by their very nature, require that the SCS technician, farm advisor, or engineer have available to him a facility for making quick, accurate, diagnostic tests.

Institute for Land and Water Management Research (Wageningen).—The director of this institute is C. van den Berg.

A visit to this institute is an absolute must for anyone working in research on drainage, and soil and water management. The institute was created partly with Marshall Plan money and partly by the Kellogg Foundation. It has adequate offices and laboratories. It is responsible for research in the field of water management (hydrology, irrigation and drainage, plant and soil water relationships), soil improvement and economics of land consolidation. This agency is doing some of the best and most fundamental research on drainage problems of any place visited. It has invested some money in a comprehensive study of rainfall, water table levels, and soils for the Netherlands. The report of this work is now in print.

It is also conducting fundamental theoretical studies of drainage phenomena, particularly the theory of evaporation from a water table and theories on the nonsteady state of drawdown for drainage design. This work is under the supervision of W. C. Visser.

International Institute for Land Reclamation and Improvement.—This institute is located in Wageningen and was founded with the aid of the W. K. Kellogg Foundation. It started its work in 1956. The director is J. M. van Staveren. Van Staveren visited the United States last year.

The institute is responsible for collecting and disseminating information on a world-wide basis with regard to drainage and land reclamation; to promote and conduct applied scientific research on reclamation; and to conduct field investigations world-wide on the feasibility of schemes for agrarian development. In effect, this agency acts as a clearing house for consulting services on agricultural problems throughout the world.

Government Service for Land and Water Use (Utrecht).—This agency in some ways is comparable to our SCS in that it provides technical assistance for farmers on individual soil and water management problems. The man in charge of the Utrecht office is C. L. van Someren.

Van Someren knows more about all types of drainage equipment, machines, tools and techniques than anyone else the author contacted. He has compiled an excellent report on tile-laying machines used throughout the world. He is also familiar with all the various techniques used in the Netherlands to measure field hydraulic conductivity, tile outlet flow, and other applied field techniques.

Research Department of the Zuiderzee Reclamation Project, (Kampen).—The headquarters for this project are at Kampen about 70 miles from Wageningen. The Director of the research, A. J. Zuur, is attached to the University of Wageningen and teaches graduate courses. Zuur is carrying on research on reclaimed soils. The so-called "ripening" of soils which have been drained and reclaimed over a period of years is most interesting and should have some application in the United States.

Reclamation of land from the sea and from tidal marsh areas began about the year 1400 and has continued up to the present time. These projects are long-range programs, and they are carried out segment by segment over a period of years at great cost. When asked how these costs are justified, the author was, in turn, asked, "How much value can you ascribe to productive land with a population density of over 800 people per mile?"

The modern day reclamation of the Zuider Zee area has been in process for approximately 40 yr. This area was once inhabited by Germanic tribes. Newly drained areas reveal the presence of villages and farms from about the year 900. It is thought that catastrophic storms from the North Sea may have inundated large areas in creating the Zuider Zee.

After World War I work was started to close off the Zuider Zee with a sea wall, dike or dam. This work was completed in 1932 and consists of a tremendous dike some 19 miles long and, in places, one-fourth to one-half mile wide. The Ijssel River, a branch of the Rhine delta outlet, flows into this enclosed area forming what is known as Lake Ijssel. The original plan was to carve four huge polders or subdiked areas from this lake. The Wieringermeer Polder of 49,420 acres was put into production in 1935-40. The Northeast Polder of some 118,500 acres was diked off and pumped dry by 1942. Despite delays during World War II, it is now a thriving enterprise. The other two polder areas are in various stages of development with an eventual development of over 500,000 acres.

It must be emphasized that these reclamation works are tremendous in scope and in detail. Not only must the dikes and pump systems be built, but the open drains, tile drains, roads and bridges must also be constructed. Buildings are constructed, trees are planted, parks laid out and people are moved in to take over. The land is leased to a family in perpetuity as long as

a male member desires to farm it. These farms are some of the most prosperous and beautiful anywhere in the world.

Obviously all this meticulous planning calls for detailed application of soil and water management. The Dutch are bringing all of their time-honored ingenuity and energy to this problem. Here, too, the industrial and urban competition for water is apparent. One portion of the Zuider Zee project is being revised to provide a large circular fresh water lake around the polders and adjacent to Amsterdam. Even the Netherlands' legendary over-abundance of water is proving to be an asset.

The Netherlands people have even more vast schemes and plan to reclaim tidal lands. They propose eventually to build an outer closing dike project that would encompass all the West Frisian Islands. If they find they have enough fresh water to promote this new project, they may add another million acres of arable land to their inhabitable area.

ACKNOWLEDGMENTS

Great Britain - E. C. Childs, School of Agriculture, Clare College, Cambridge, England.

Denmark - H. C. Aysling, Hydrotechnic Institute, Royal Veterinary College, Copenhagen, Denmark.

Netherlands - F. Hellinga, Head, Dept. of Land Drainage and Land Improvement, 1 Duivendaal, Wageningen, Netherland.

Journal of the
IRRIGATION AND DRAINAGE DIVISION
Proceedings of the American Society of Civil Engineers

WORLD PRACTICES IN WATER MEASUREMENT AT TURNOUTS

By Charles W. Thomas,[1] ASCE

SYNOPSIS

Measuring devices at farm turnouts on open channel irrigation systems are discussed under six general functional classifications. Illustrations of each classification in use in different parts of the world are cited. Conclusions regarding the type of device best suited to meet local requirements are not drawn. However, by directing attention to the different techniques followed, a design incorporating the desirable elements of several of these techniques might eventually be developed.

INTRODUCTION

Successful operation of an irrigation system depends on adequate control and measurement of flows. At no place is this more important than at the farm turnout. It is at this point that the individual user and the operators meet. On any irrigation system, the largest number of structures of any one type are the farm turnouts. There are some 85,000 on lands served by systems built by the United States Bureau of Reclamation, Dept. of the Interior, and another 75,000 are to be found in irrigated areas served under the Warren Act and special lands. Outlets on canals in the Punjab region of India and Pakistan numbered over 41,000 before 1950 and more have been added since that time. Such facts should indicate the importance of these structures and the reason for drawing attention to the means of controlling and measuring flows through them.

Note.—Discussion open until November 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers, Vol. 86, No. IR 2, June, 1960.

[1] Hydr. Engr., Bur. of Reclamation, U. S. Dept. of the Interior, Denver, Colo.

There are many considerations to be taken into account in the selection of a control and measuring device to best fit conditions at the site. Loss in head, economy of installation and maintenance, range of discharge to be handled, legal requirements, are among the factors that make the selection difficult.

DESIGN AND OPERATION OF IRRIGATION SYSTEMS

General.—A review of some of the general aspects of irrigation systems is helpful to appreciate fully and understand the problems associated with control and measurement of water at the farm turnout.

Good design of an irrigation system is based, primarily, on making maximum use of the water resources available. In general, the land area that may be irrigated is established by the amount of water resource. By proper regulation and control of the water, the area served may be extended.

In the design of the system, the quantity of water to be conveyed is based on the acreage to be served. A study of rainfall, soil types, crops that may be grown, depth to the water table, and other factors determine this quantity.

Method of Distribution of the Water.—To make the best use of the water in the irrigation system, the designer must consider its distribution. One of the following general methods may be used:

1. Continuous flow deliveries
2. Rotation or intermittent flow
3. Demand deliveries
4. A combination of these methods.

In an irrigation system designed for continuous flow, each irrigator is supplied his share of water in a continuous stream. This results in large land owners receiving large flows and small owners small flows. To measure the delivery at each turnout, devices in the system would necessarily vary in size.

The rotation or intermittent flow system is based on delivering a fixed amount of water to each farm at definite intervals. Storage reservoirs are necessary to make the water available and permit delivery at definite intervals during the irrigating season. Systems, deriving their source of water from normal stream flow, must make deliveries at the time the water is available. A more standardized size of measuring device can be used under this system and, often, a saving in the number of measuring devices could result.

The demand-delivery system is designed to make water available at all the farm turnouts on call or demand by the farmer. It is certainly the most convenient and economical from the consumers' standpoint. If adequate storage and ample conveyance capacity are provided, and if there is sufficient control of flows to avoid wastage en route or off the end of the system, then the deliveries can be made on a call or request by the farmer. This system of delivery is not adaptable to projects operating without storage facilities. For such projects the water must be used when available and cannot be supplied to meet the demands of individuals. Measuring devices can be standardized, to some degree, under this system. Control is of major importance.

Some irrigation projects operate with a combination of these systems. During periods of high seasonal runoff, the main conveyances are usually operated to capacity if the demand exists and if there are legal rights to the water. At such times, at least a major portion of the farmers desiring water can be served. When storage reserves are being drawn upon, the project may operate on rotation or demand.

Other combinations of means of distribution may be used. Combinations of distribution methods cause added problems in control and measurement.

Charges for Water.—The charges made for water supplied from the irrigation system vary considerably throughout the world. There are, however, four general charging categories into which the majority of systems will fall.

The first system is a charge based on the rate of flow. This necessitates a rate of flow measurement and adequate records. The second, a volume basis, necessitates a volumetric measuring device or a rate-of-flow device combined with a time record of deliveries. The third method is a charge based on the acreage of crops matured. The rates vary in accordance with the crops grown. Such items as the amount of water necessary to produce a certain crop, the season when most water is necessary for the crop (winter or summer), the value of the crop and comparative cost of irrigation from wells or other means, all enter the formula from which the charge is derived. Measurements of flow as a basis for charges are not necessary under this system, but adequate control must be exercised to insure equitable distribution. The fourth method is a charge based on each irrigation for a given area. In climates that do not demand continuous irrigation for the successful growth of crops or in locations in which the same crop is grown in large areas year after year, a fixed charge is possible. This system is practiced extensively in rice-producing areas.

Operating Organization.—In many areas of the world, there is, generally speaking, a large organization to control the conveyance and delivery of the water, to regulate the flows, and to keep records necessary for charges.

In other parts of the world, especially in India and Pakistan, there is generally no manual control on the farm turnouts. The design is such that they work automatically and continuously. In the Punjab area, the lateral systems, with a maximum capacity of from 300 to 400 sec-ft, are so designed that manual control or regulation is not necessary at any point in the system except at the turnout from the main canal. The internal distribution of water among the various cultivators on the laterals is generally managed by the cultivators themselves, and the government, which operates the canals, keeps no records of the farm deliveries.

METHODS OF MEASUREMENT AND CONTROL

From the foregoing presentation, it may be seen that the operation of an irrigation system could be simplified and many of the problems of controlling and measuring the water delivered to the consumers could be solved if some reliable means were available to deliver automatically a fixed, predetermined discharge to each consumer under the system. Technicians have been striving for many years to devise such a device. Many of the schemes offered have never outgrown the paper stage. Others have proven worthless in actual practice or have been discarded because of their complexity and unreliability. There are, however, some methods of treating the problem that have met with success.

The Six General Schemes.—Knowledge acquired by the author during extensive travel assignments, and through studies made on advanced research fellowship in France suggests that measuring devices at the farm turnout may be classified broadly according to their operation. For the purpose of this discussion, these measuring devices are divided into six broad functional classifications. No clear lines can be drawn between these selected classifications, and some examples given overlap into other categories.

The six general classifications are: (1) those devices, sometimes referred to as modules, that will automatically deliver a constant, or near constant, discharge over a range of changes of both upstream and downstream water levels; (2) those devices, sometimes referred to as semimodules, that will automatically deliver a constant, or near constant, discharge over a range of downstream levels but in which the discharge will vary with changes in the upstream water level; (3) those devices that provide an equitable distribution of flow over a range of fluctuations of upstream water surface levels (these devices are generally semimodules); (4) those devices designed to deliver, automatically, a constant discharge when operated in conjunction with auxiliary equipment to control the upstream water level and that are not affected, within limits, by changes in downstream levels. (5) the structures and equipment, in general use in the United States, that give a range of discharges depending on upstream and downstream heads and which may require auxiliary means of manual control; and (6) those devices that do not serve as controls, but which totalize the discharge, over a relatively wide range of flows passing them, and, thus, provide an equitable basis for charges.

It is not the intent of the author to attempt an explanation of the exact design and operation of the various devices mentioned or to argue the many advantages or possible weak points of each. The classification has been made on a functional basis and it is assumed that if the device, structure, or combination installation is designed, constructed, and operated as intended, the function will be fulfilled.

The examples cited constitute only a minor portion of all those developed or suggested. There are many others throughout the world and, possibly, many of those not mentioned are more popular.

Modules.—As previously stated, a device that would automatically deliver the desired quantity of flow to the farm regardless of fluctuations of water surface in the conveyance system or in the farm ditch would very nearly solve the problem of control and measurement at the farm turnout.

Many of the old irrigation networks of the world operate on direct flow from the streams without benefit of seasonal storage. Many of these systems are quite extensive. Such operation causes considerable fluctuation in water levels in the conveyances. In periods of high seasonal runoff, the canals may be operated to capacity, but as the stream flow subsides, the quantities available for diversion become limited and the canal levels fall. In these areas, much work has been done toward evolving a turnout to meet these conditions.

S. I. Mahbub and N. D. Gulhati have traced the history[2] of evolution of various types of turnouts on the canals of the Punjab in India and Pakistan. Operation of some of the large canal systems in this area began shortly after 1800. The authors define the module as a device that will deliver automatically a fixed quantity of water regardless of fluctuations of levels of water surface, within limits, in the canal or in the delivery. They cite a number of such devices in use. Some are constructed with moving parts and others without.

One such device cited, that has no moving parts, is known as the Gibbs Module, Fig. 1. The water is lead through an inlet pipe to a spiral rectangular trough that is level and covered. Free vortex flow develops in this eddy chamber with a consequent rise in water surface at the outer wall. A number of cross baffles, with bottom edges sloped, correctly serve to skim off part of the

2 "Irrigation Outlets," by S. I. Mahbub and N. D. Gulhati (revised and enlarged by N. D. Gulhati), Atma Ram & Sons, Kashmere Gate, Delhi, India, 1951.

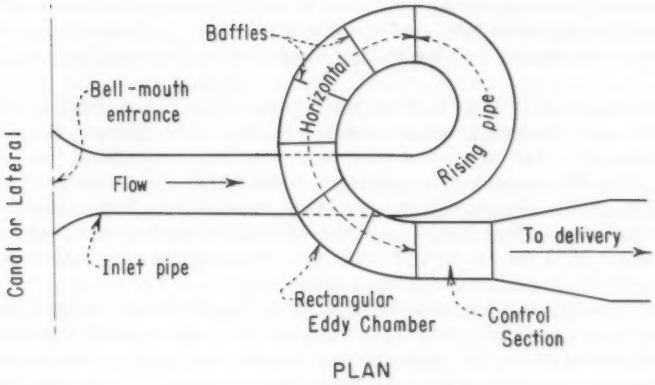

FIG. 1.—GIBB'S MODULE

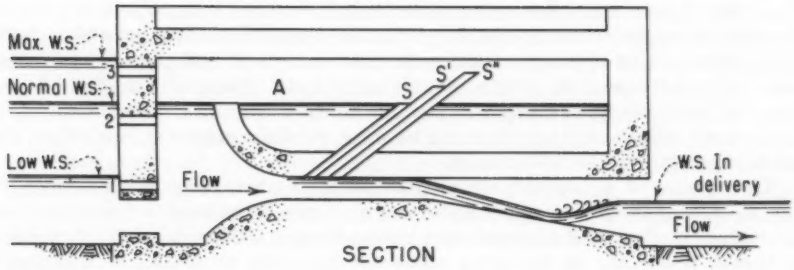

FIG. 2.—KHANNA'S RIGID MODULE

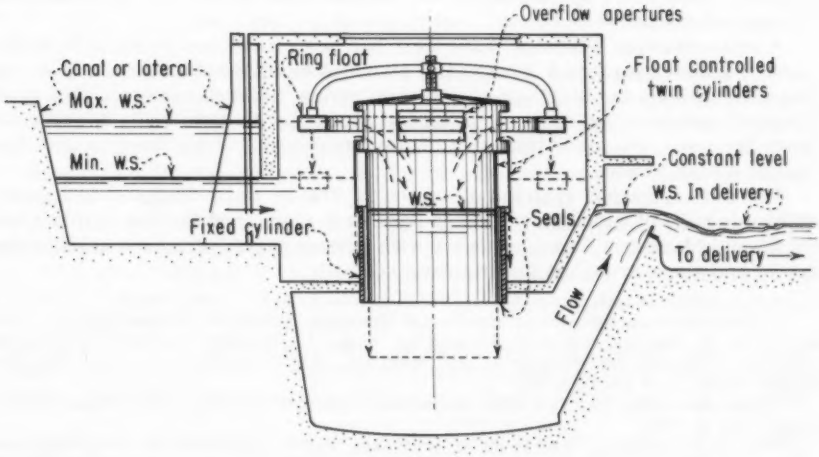

FIG. 3.—MODULE WITH MOVING PARTS

flow and turn it back on the approaching flow. This action becomes more pronounced as the upstream head and the velocity in the chamber tend to increase. An impingement results and the velocity is lowered, thus holding the discharge constant.

The design is such that the flow passes through critical depth at the downstream end, and changes in water surface levels in the delivery do not reflect in the discharge. The degree of turn of the spiral depends on the volume of discharge and the variation of upstream head being designed for and varies from 180°, to 540°. Standard designs of this module have been developed in the hydraulic laboratory for discharges and conditions so that the variation from design discharge is said to be not more than 3%. A more complete description[3] is given by D. V. Joglekar and S. D. Phansalkar.

Another example is Khanna's Rigid Module, Fig. 2. Water enters the structure through the openings marked 1, 2, and 3. As long as the water surface in the canal remains above the main opening, the turnout acts as a submerged orifice. When the upstream water surface rises to opening 1, some eddies are formed at the entrance and the flow is reduced below that which would normally be discharged with the increased head. Additional upstream head causes chamber A to fill, and water flows successively into the inclined slots, S, S', and S", causing an impingement on the forward flow through the opening and a consequent reduction in discharge. Considerable analytical and empirical development were necessary to obtain the correct relationships of size and slope of slots to produce the desired results. Limited changes in downstream water level do not affect the measurement because the flow passes through the critical depth at the exit of the turnout.

An example of a recently developed module with moving parts is shown in Fig. 3. Changes in upstream water level cause movement of the float that maintains the flow at a constant rate automatically. Considerable variation in upstream level may be tolerated since the float may be adjusted. Changes in downstream water levels do not alter the rate of flow if the maximum level in the delivery does not exceed the level of the fixed weir at the outlet of the distributor. This exit weir, developed in Italy, has been calibrated for measuring the rate of discharge.[4]

A self-adjusting, standing, wave weir has been developed in Egypt.[5] In this device, a float operates a linkage and gear system that automatically and continuously adjusts the length of the weir to give a fixed discharge with a given range of upstream water level. A sloped section, with side-walls downstream from the weir, prevents influence of the downstream water level on the discharge within limits.

The old irrigation systems of southern France were designed to operate without benefit of storage. Modules have been developed for use in this area. On the old Marseille Canal, modules with moving parts were once used extensively and some are to be found today.

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[3] "Hydraulic Structures on Irrigation and Drainage Systems for Measurement of Water," by D. V. Joglekar and S. D. Phansalkar, Paper 19, Question 9, Third Congress on Irrig. and Drainage, San Francisco, 1957, Internatl. Comm. on Irrig. and Drainage, 104, Sunder Nagar, New Delhi, India.

[4] "New Automatic Channel Flow Regulator," Anonymous, Water and Water Engrg., June, 1956, p. 250.

[5] "The Self Adjusting Weir," by M. Elmadani, Paper 2, Question 9, Third Congress on Irrig. and Drainage, San Francisco, 1957, Internatl. Comm. on Irrig. and Drainage, 104, Sunder Nagar, New Delhi, India.

Semimodules.—A semimodule is a device that will pass a fixed discharge, provided either the head water or tail water remains constant. Most of such devices are designed in such a manner that changes in tail water conditions do not reflect in the rate of discharge. Variations in upstream water surface elevations will, however, change the discharge rate. Such a device is, theoretically, better than one that is sensitive to variations in both upstream and downstream water levels.

Starting with a turnout consisting of a cut, and later, a barrel passing the canal bank. Both were subject to changes in discharge with changes in both upstream and downstream levels, the next step would normally be to envolve a device of the semimodule type.

In many parts of the world, the water user's interference with the turnout led to placing checks, cisterns, orifices, and similar structures at the downstream ends of the turnouts to raise the water surface to a level that would be above the maximum level in the delivery channel. Thus, the turnout would not be affected by operational changes made by the water users.

In the Punjab, the Harvey-Stoddard Improved Irrigation Outlet, Fig. 4, was developed as one such type of device. A fixed crest weir maintains the level at the end of the turnout above the maximum water level in the farm delivery. In the same area, the open flume type of turnout was modified by placing a roof block in the flume, Fig. 5, to cause the flow to pass through critical depth and thus not reflect changes, within limits, in downstream levels. Further description and details of semimodules may be found in a paper[6] by Hamid.

Weirs placed in the conveyance downstream from the turnout, as used in the United States, are not included in this classification. Although the weir does not prevent changes in the downstream levels from affecting the flow through the turnout, provided the weir is not submerged, the weir structure is nearly always separated from the turnout structure and the control remains at the turnout gate.

Equitable Distribution of Flow.—This type of measuring device is so designed that the levels in the conveyance system may vary over a wide range, and all deliveries will remain proportional. This insures an equitable distribution without providing a control device at each individual turnout for periodic regulation.

In areas where charges are based on acreage of crops matured or where water is distributed in the quantity available on the basis of land areas irrigated or for other reasons, an equitable distribution of the available water to the users may suffice. In the Punjab, for instance, measurement is made at the head of the lateral and equitable distribution serves as a basis for farm deliveries.

Open flume turnouts of the type shown in Fig. 6 serve this condition quite well. The entrance is shaped so that an equitable share of the flow is extracted. Exit conditions are such that changes in downstream level are not reflected to an appreciable degree. Many barrel-type turnouts, to serve a similar purpose, have been developed.

Divisors are used in many parts of the world to effect equitable distribution of flow. These structures divide the flow into the desired proportions. To be effective, upstream and downstream flow conditions must be similar across the

[6] "Distribution and Measurement of Irrigation Supplies in West Pakistan," by Chowdhry Abdul Hamid, Paper 18, Question 9, Third Congress on Irrig. and Drainage, San Francisco, 1957, Internatl. Comm. on Irrig. and Drainage, 104, Sunder Nagar, New Delhi, India.

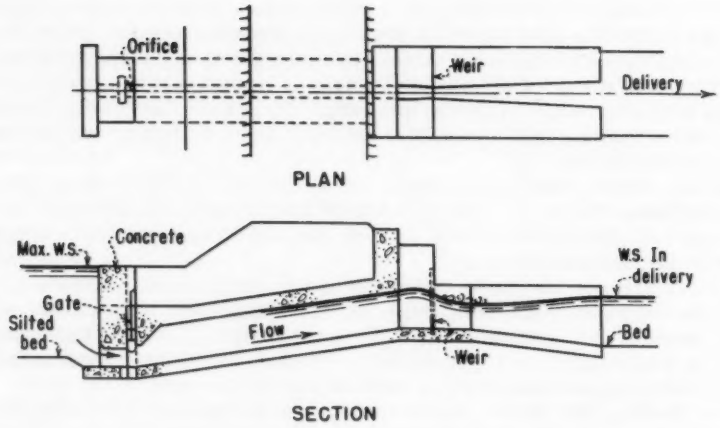

FIG. 4.—THE HARVEY-STODDARD IMPROVED IRRIGATION OUTLET

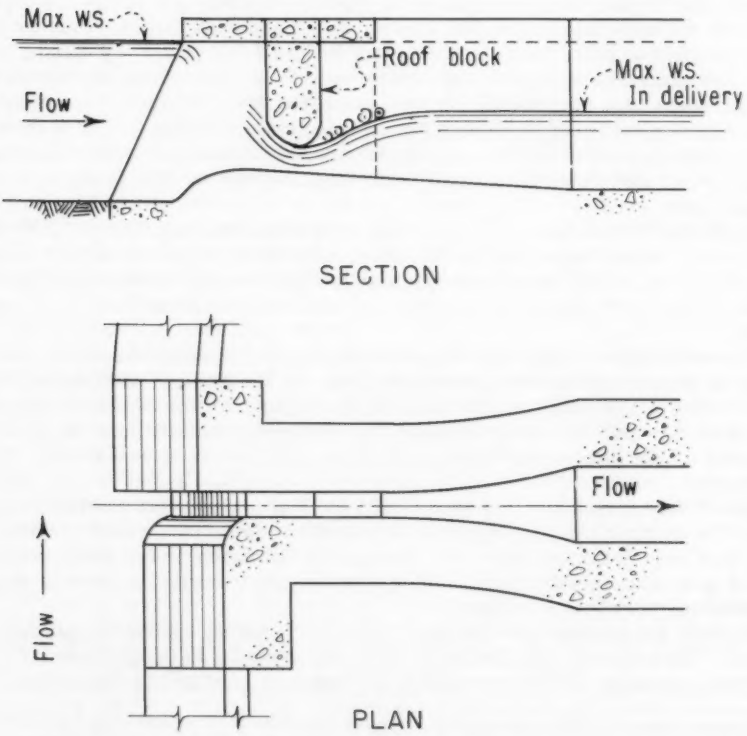

FIG. 5.—A STANDARD DESIGN OF SEMI-MODULE USED IN THE PUNJAB

section. The dimensions of the openings are not necessarily in the same proportions as the desired division of discharge. They may be made rigid or variable. Fig. 7 shows a divisor in an old irrigation system near Marrakech, Morocco. This structure also serves the purpose of slowing the flow, that is above critical velocity, for diversion into the turnout.

In other irrigation networks in southern Europe and North Africa, a divisor developed in France is used (Fig. 8). The dividing blade is adjustable and calibrations are made so that the flow may be proportioned between the two channels in varying amounts. The standard setting for channels on fairly flat gradients is illustrated in this figure. When steep slopes are encountered, the setting is slightly different.[7]

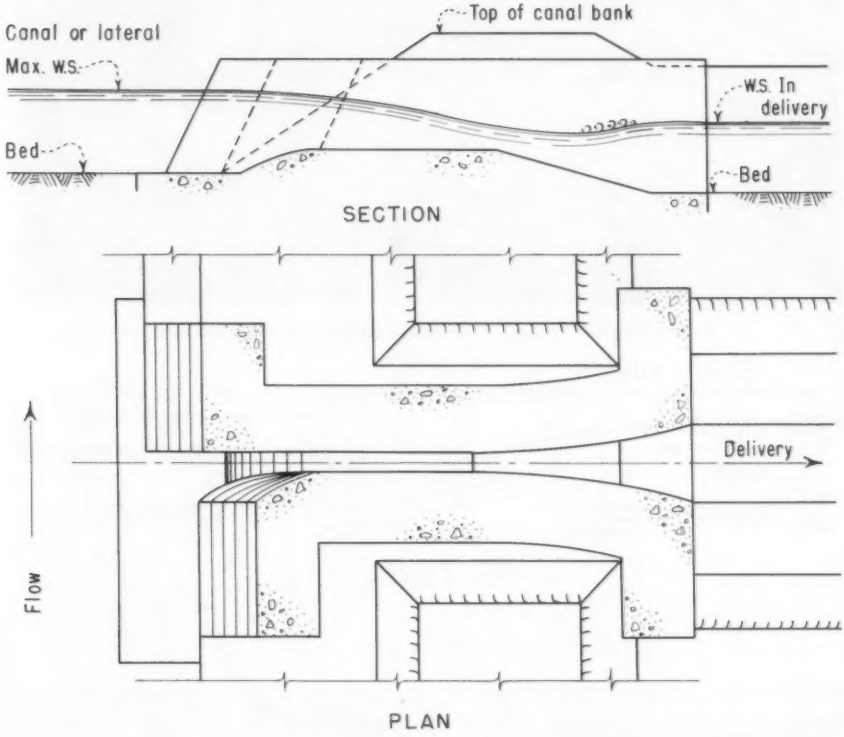

FIG. 6.—CRUMP'S OPEN FLUME OUTLET

In many of the old irrigation systems in the United States, "division boxes" were used. There were generally constructed of wood. Many of them were of fixed proportions. One type of adjustable divisor is shown in Fig. 9. This particular structure, as well as others of similar proportions, was calibrated for flow measurement at different settings over a range of upstream heads.[8]

[7] "Quelques Considerations sur l'Equipment des Reseaux d'Irrigation NEYRPIC," Grenoble, France.

[8] "Divisors (for the measurement of irrigation water)," by V. M. Cone, Bulletin 228 of the Agric. Experiment Sta. of the Colo. Agric. Coll., Fort Collins, Colo., April, 1917.

FIG. 7.—DIVISOR IN OLD IRRIGATION SYSTEM IN MOROCCO

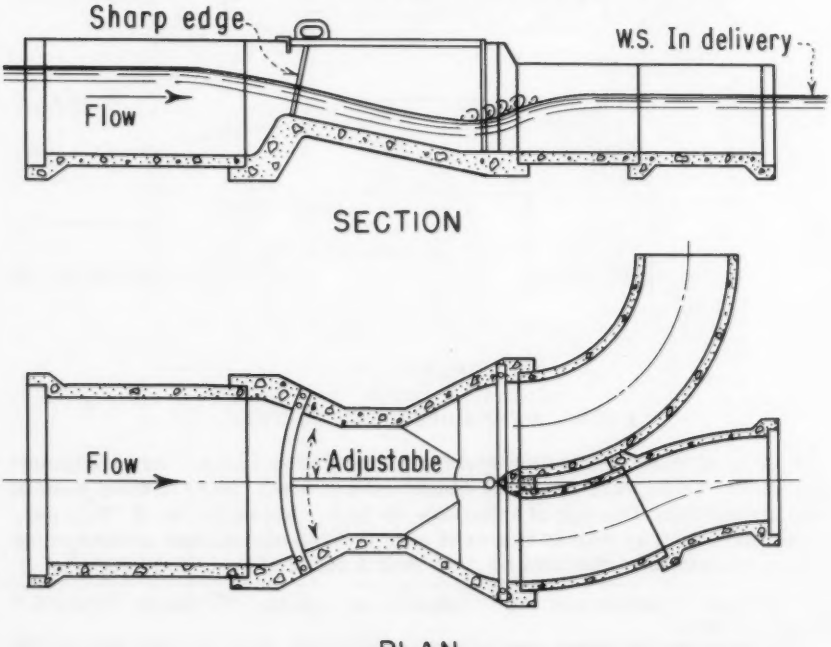

FIG. 8.—FRENCH TYPE PROPORTIONAL DIVISOR

Semimodules With Auxiliary Apparatus.—The design of a turnout that will deliver a fixed quantity of water and not be subject to variations of upstream and downstream water levels may become very complicated as the examples cited would indicate. Such devices may also be subject to operational difficulties. The effects of changes in downstream water levels can be removed by relatively simple design. It would seem then that the use of auxiliary equipment to control the level upstream would effect a workable solution.

Examples of distributors that will deliver a near constant quantity will first be explained, followed by examples of auxiliary means employed to control, automatically, the water surface upstream from the distributor to a near constant level, and negate the need for periodic regulation of each turnout.

The distributor shown in Fig. 10 is used extensively in southern Europe and North Africa and, to a lesser extent, in other parts of the world. The sliding plates are either fully open or fully closed. The desired discharge is obtained

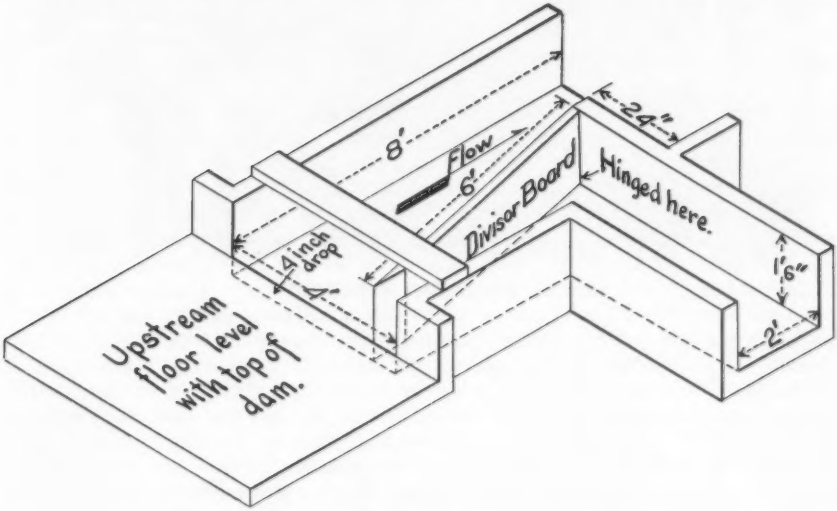

FIG. 9.—U. S. TYPE PROPORTIONAL DIVISOR

by opening one or more of the passages. It may be seen from the cross section in Fig. 11 that each section of the distributor is formed by a specially shaped sill and a fixed plate. The sill and fixed plate are contained between vertical parallel side plates, thus creating an orifice.

If the water level above the orifice is controlled to permit variation between predetermined limits, the discharge that passes through the orifice remains nearly constant. The stability of the discharge is maintained because the increase in velocity, that results from the increase in head, is accompanied by a greater degree of contraction of the outgoing stream. A discharge curve is included in Fig. 11.

The downstream slope of the sill causes the formation of a hydraulic jump in which part of the kinetic energy is recovered. Thus, the overall loss in head through the apparatus is low. The formation of the hydraulic jump also makes

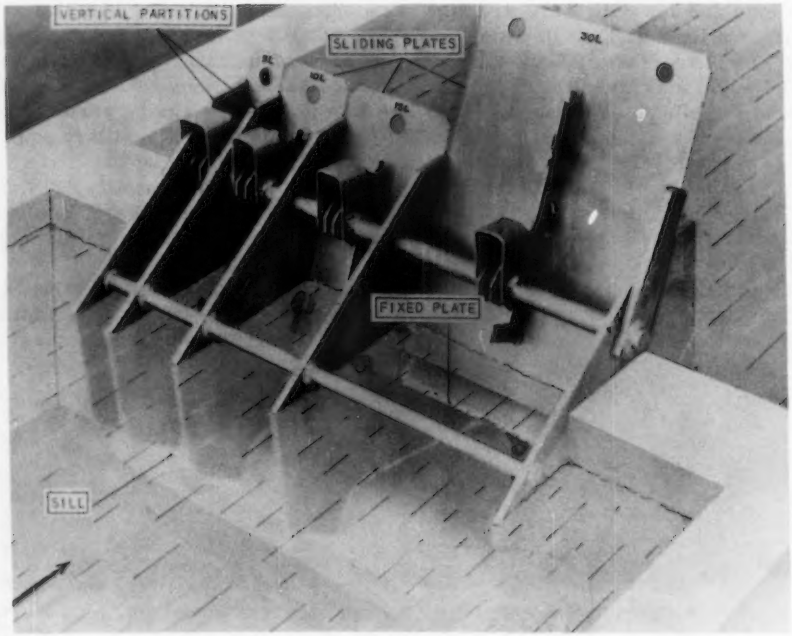

FIG. 10. DISTRIBUTOR (FRANCE)

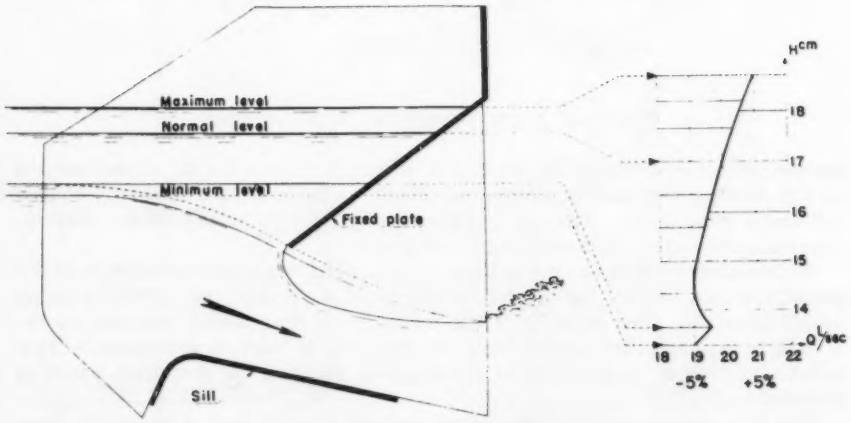

FIG. 11.—DISCHARGE CURVE OF DISTRIBUTOR

the discharge independent of the downstream water level as long as the jump is not drowned.

Another distributor designed along very similar lines is shown in Fig. 12. The distributor can absorb a greater change in upstream level because of the action of the siphon and the consequent added impingement on the jet. A discharge curve is also shown in the figure. Although developed in France and in North Africa, these distributors have been studied in other parts of the world.[9]

A number of schemes have been devised for controlling automatically the water surface in a canal or lateral. They may be used in conjunction with distributors. A balanced radial gate with a float attached to the upstream skin plate, Fig. 13, automatically provides a nearly constant water surface upstream from the gate. This automatic control gate is installed in the canal or lateral just downstream from the turnout equipped with a distributor.

A balanced gate for automatically controlling the level downstream from the installation has also been developed (Fig. 14). The float, in the foreground, automatically positions the gate leaf over an orifice to maintain a predetermined, near-constant level. This gate is used on storage reservoirs or on turnouts from canals in which the water level varies. The distributor is placed downstream from this gate (Fig. 15).

In Algeria and Morocco, where the newer conveyances consist, generally, of precast concrete sections, other means are used to control the water surface to a near constant level. Long, diagonal weirs, Fig. 16, and "duckbill" weirs, Fig. 17, are employed. The "duckbill" weir is also used in conventional lined sections. The distributors are installed upstream from these devices.

Another development for controlling water surface automatically is a float operated, disc valve that may be used on a turnout fed from a source that has a variable level.[10] The distributor is located downstream from the valve. Fig. 18 shows a large installation to illustrate this type. The valves are usually applied to smaller installations, but work equally well in the larger sizes.

Measuring Devices in Common Use in the United States.—In the United States, water is usually distributed on the basis of rate-of-flow, in most instances cubic feet per second, although this rate, combined with time, may be used to give a volume, in acre-feet, as a basis for charges. Weirs, critical depth structures, Parshall flumes, and similar means of measurement require that the head be known to obtain discharge. When the water surface in the conveyance is permitted to fluctuate, adjustment of a turnout gate or similar installation is necessary to obtain the desired head at the point of measurement. The usual practice is to make this adjustment daily and then obtain a reading of head on the measuring structure to serve as a basis of charges and to control distribution.

As a general rule, only the larger metering stations are equipped with apparatus to record the head continuously at the measuring section. Farm turnouts are thus excluded. An exception to this practice may be found in areas in which the cost of water is high. Because the discharge varies with the head and the head is subject to variations with changes of water level in the canal or lateral, assuming the operator is not present at all times to adjust the turnout gate, it is probable that the rate-of-flow does not remain entirely constant

[9] "Automatic Regulator to Obtain Constant Discharge in a Channel for a Widely Varying Income Flow," by Mushtaq Ahmed, Mian Muzaffar Ahmed, and S. A. Awan, Paper 5, Question 9, Third Congress on Irrig. and Drainage, San Francisco, 1957, Internatl. Comm. on Irrig. and Drainage, 104, Sunder Nagar, New Delhi, India.

[10] "Amenagement de la Basse Moulouya (Maroc oriental)," by Florent Granger, Terres Et Eaux, No. 26.

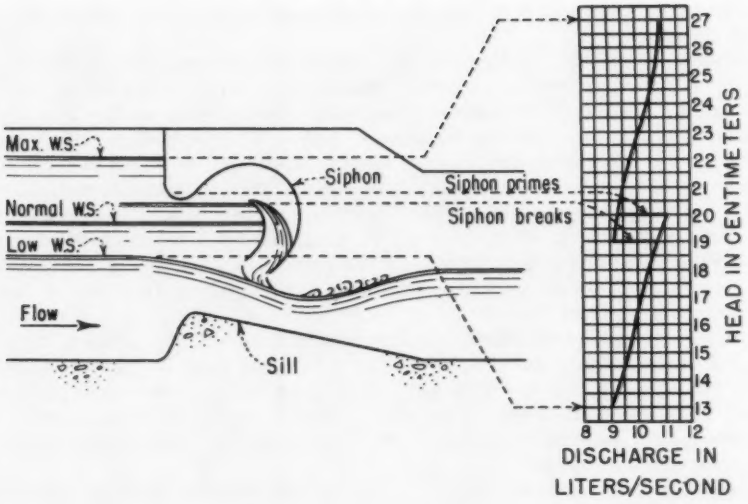

FIG. 12.—DISTRIBUTOR WITH SIPHON

FIG. 13.—CONSTANT UPSTREAM LEVEL AUTOMATIC GATE

during the interim between observations of the gage height. Because major changes in flow are not made over short periods of time, the rate of discharge at the turnout remains relatively constant. However, a continuous record of gage height would be desirable. The present cost of providing such a record at each farm turnout is not justifiable in most systems.

Generally speaking, the measuring devices employed at farm turnouts on open channel systems are designed to permit variation of the upstream head

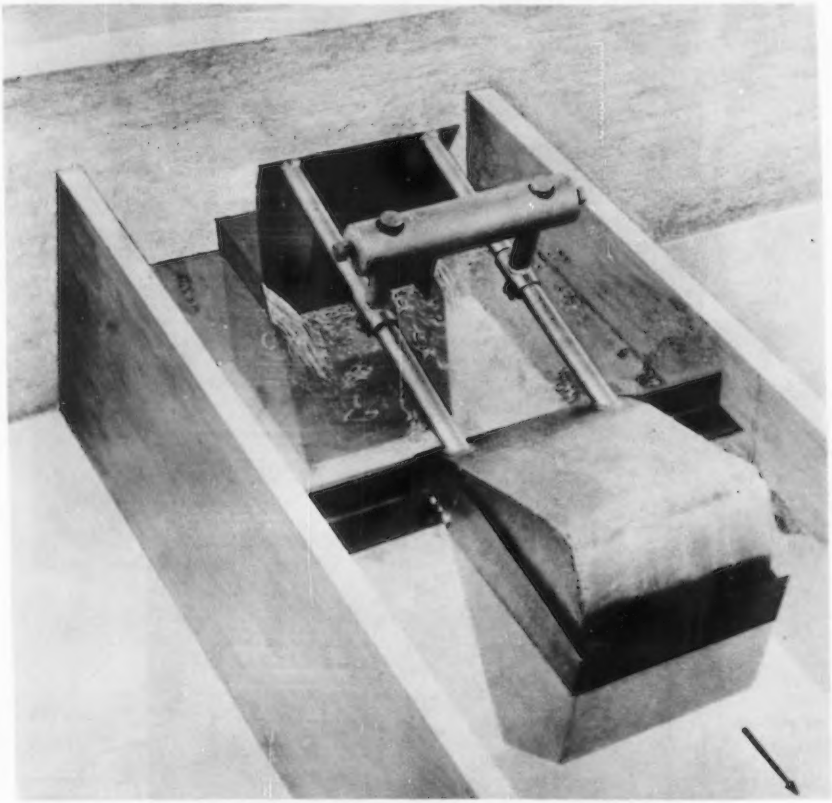

FIG. 14.—CONSTANT DOWNSTREAM LEVEL AUTOMATIC GATE

and, in most cases, variation of the downstream head. Observation of the upstream head or the differential head and the use of tables or curves prepared from previous calibrations permit evaluation of the discharge. Regulation of the head is, almost without exception, by manual control.

There are installation in which the water levels in canals and laterals are controlled automatically, but this automatic control has not reached to the farm turnout. The controls are usually employed to raise the water surface a sufficient amount to permit deliveries and not necessarily to provide a constant head on the delivery. Examples of automatic control are to be found, but these are exceptions.

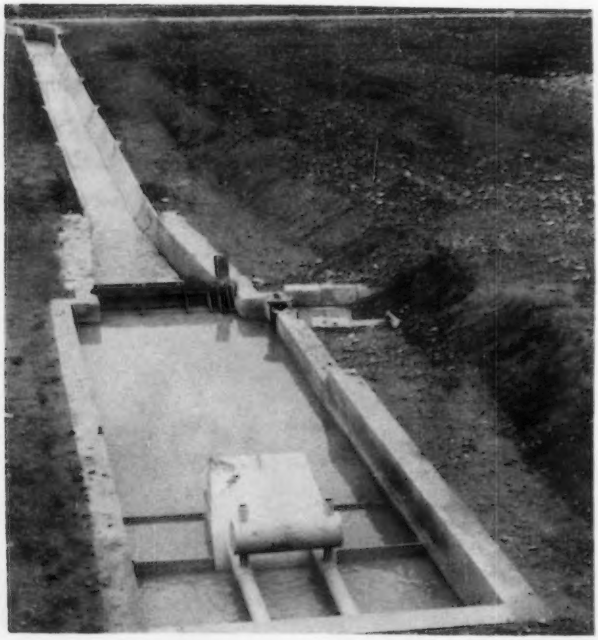

FIG. 15.—CONSTANT DOWNSTREAM LEVEL AUTOMATIC GATE AND DISTRIBUTOR

FIG. 16.—DIAGONAL WEIR IN PRECAST CONCRETE LATERAL

FIG. 17.—DUCKBILL WEIR IN PRECAST CONCRETE LATERAL

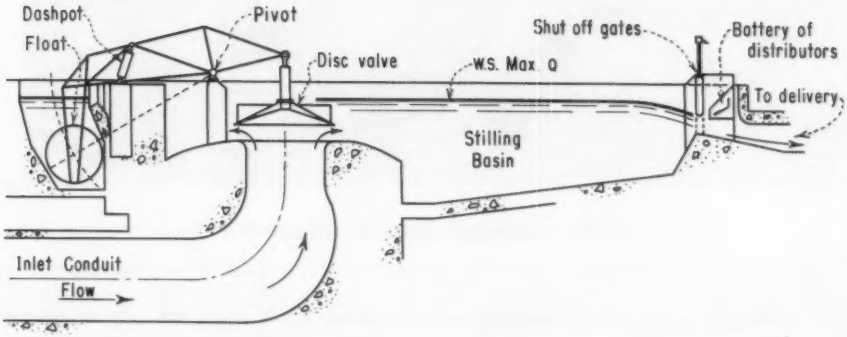

FIG. 18.—DISC VALVE CONSTANT LEVEL REGULATOR

It would not be consistent to evaluate the measuring devices in use in the United States with regard to their operational characteristics, because those devices mentioned previously have not been evaluated completely. However, the equipment and structures in common use will be mentioned and some evaluation will be made to illustrate usage. Design and operational details, calibration data, and discussion of general usage may be found elsewhere.[11, 12]

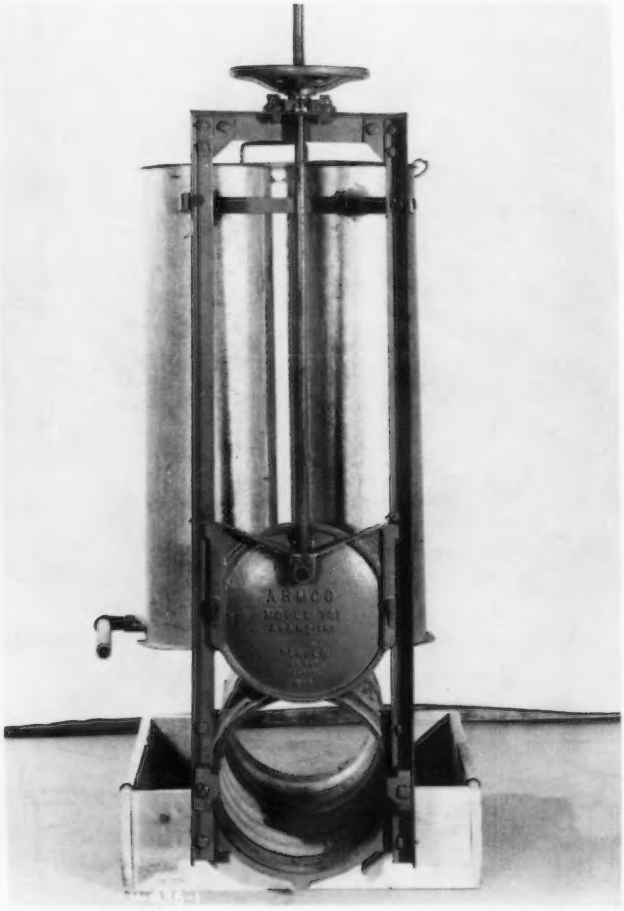

FIG. 19.—TWELVE-INCH METERGATE

11 "Water Measurement Manual," Bur. of Reclam., U. S. Dept. of the Interior, Denver, Colo., May, 1953.

12 "Structures and Methods for Measuring Irrigation Water," by Charles W. Thomas, Paper 9, Question 9, Third Congress on Irrig. and Drainage, San Francisco, 1957, Internatl. Comm. on Irrig. and Drainage, 104, Sunder Nagar, New Delhi, India.

A shutoff is, in most instances, required at a farm delivery because of the manner in which the systems are operated. Economy in installation can be effected if the shutoff also serves as a regulator and as a means of measurement. There have been numerous attempts to provide this combination.

Many irrigation systems have been equipped with meter gates such as the one shown in Fig. 19. One of the stilling wells is connected to the water prism in the canal and the other to the delivery pipe on the downstream side of the gate. The difference in water levels in the two wells and the gate opening is

FIG. 20.—CONSTANT HEAD ORIFICE TURNOUT

measured and the discharge obtained from tables developed from standard calibrations.[13] The total head loss is low. The initial cost is low compared with other means because of the combined features of measurement, regulation, and shutoff. Periodic observations and manual adjustments are necessary. Changes in either upstream or downstream water levels alter the rate of flow. Other

13 "Water Measurement Tables for the Armco Metergate," Armco Drainage and Metal Products, Denver, Colo., 1951.

types of gates have been calibrated, but the tables are not as complete and the gates are not as well standardized.

The constant head orifice turnout shown in Fig. 20 has become popular for measuring farm turnouts as well as installation in canals and laterals. The operation is manual. Calibration and standardization have been accomplished in the smaller sizes. The upstream gate is set at the required opening, as shown in the rating tables, to deliver the desired quantity. The downstream gate is regulated until there is a 0.2-ft differential head across the upstream gate as indicated by two enameled scales, one located upstream from the upstream gate and the other between the gates. Any change in water surface level in the canal or delivery is reflected in the measurement. Periodic regulation and observation are necessary.[10]

The Parshall measuring flume,[14] Fig. 21, is a critical depth measuring device. It was developed empirically, standardized, and calibrated. Hence, if the standard dimensions are followed within close tolerances in the field, the discharge is quite accurate when obtained from observing the depths of flow on the gages and use of the calibration tables. The flume is a semimodule when set high enough to operate with no backwater. Because the flow passes through critical depth in the flume, changes in tail water levels do not alter the discharge appreciably. The flume has been calibrated to operate in a low level position. Under this condition, a high degree of submergence can be tolerated and the measurement will retain its accuracy. The depth of flow in the converging section and at the throat is necessary to obtain discharge when operating with submergence. If operating submerged, changes in either upstream or downstream levels will change the rate of discharge.

The device used most extensively in the United States for measurement of deliveries to the farm is the sharp crested weir. The Cipolletti, Fig. 22, is perhaps the most frequently used type, however, a number of rectangular weirs, both contracted and suppressed, may be found. If discharges from small turnouts are to be measured, a V-notch weir is used. The weir, when operated under normal conditions (that is, with a free-falling nappe and without submergence), together with the turnout gate may be considered as a semimodule. Changes in water level in the delivery do not reflect in the measurement unless the level exceeds the height of the fixed crest. Any change in upstream level results in a change of discharge.

Adjustable length weirs are used in many installations to avoid errors in measurements introduced by small errors in observation of head when low flows are passing. By shortening the weir, thereby increasing the head for a given discharge, the percentage error is reduced.[15]

Devices That Provide an Equitable Basis for Charges.—A sixth functional class of measuring devices are those that do not, in themselves, control the flow but are operated in conjunction with separate controls and provide a totalized record of the flow volume that passes. They are effective over a considerable range of discharges and are not affected by changes in water levels upstream or downstream, provided the downstream level does not fall below a predetermined limit and the differential head lies between certain rather broad limits. The totalized record of the volume of flow, that may vary over considerable range of discharge, provides a direct, equitable basis for charges.

---

14 "Improving the Distribution of Water to Farmers by Use of the Parshall Measuring Flume," by R. L. Parshall, Colo. Agric. Coll. Experiment Sta., Fort Collins, Colo., Bulletin 488, May, 1945.

15 "Errors in Measurement of Irrigation Water," by Charles W. Thomas, Transactions, ASCE, Vol. 124, 1959, p. 319.

FIG. 21.—PARSHALL MEASURING FLUME

FIG. 22.—CIPOLLETTI WEIR

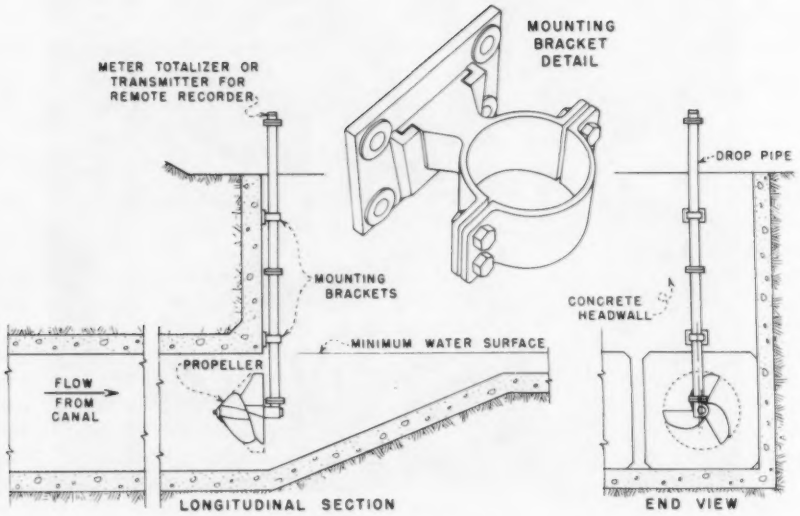

FIG. 23.—OPEN-FLOW METER ON FARM TURNOUT

FIG. 24.—DETHRIDGE METER

Velocity, turbine, and positive displacement-type meters with totalizing mechanisms are in use throughout the world on closed conduit systems. There are also many installations on closed systems where instruments are employed in conjunction with the measuring equipment to provide a record of upstream water levels or differential levels. Some of these may also be found on open channel systems at the farm turnout.

A measuring device that is now being used on irrigation turnouts in the western United States is the open flow, velocity-type, meter, Fig. 23. The propeller drives an appropriate gear train with mechanical connection, to operate a totalizer which registers, in acre-feet or other units, the volume of water passing through the turnout irrespective of variations of head. Some irrigation systems which operate on a rotation basis also rotate the meters. Some operators rotate the meters, but have a totalizing unit for each turnout that remains locked to the turnout.

The Dethridge meter is used extensively in Australia.[16] This volumetric meter consists of an undershot water wheel operating with small clearances in a specially shaped reinforced concrete flume (Fig. 24). The quantity of water passing through the meter over a period of time is recorded directly in acre-feet by a specially geared revolution counter linked to the axle of the wheel. Thus, a direct and equitable basis of charges is provided.

In Algeria, some of the larger installations that have automatic water level control equipment and distributors use recorders employing the shutoff device to provide a record of the time that it is either open or closed (normal operation). This practice is being extended to the smaller turnouts. An equitable basis for charges is thus provided. This system introduces an extra step in computing charges that is not included in the use of the totalizing meters that register volume directly.

NEW DEVELOPMENTS

In the United States, the recent development of a vane meter shows some promise of success. The meter employs an elongated, roughly triangular-shaped vane. The sides of the triangle are curved toward the other and the vane is slightly convex in the direction of flow. The apex of the triangle is down and reaches into the flow. This meter is designed to indicate the rate of flow on a graduated scale as sensed by the vane in accord with the velocity and position of the water surface. In operation, the meter will be placed in a structure of rectangular cross section in which the water surface level need not remain constant. It is proposed that the instrument will be standardized, calibrated, and assembled to cover a range of flows adequate to meet the needs at farm turnouts.

CONCLUSIONS

The evolution of design of measurement and control devices for farm turnouts has progressed independently in widely separated geographic areas of the world. The result is an abundance of available designs. These may be classified into six general types. Each design has been developed to meet the demands of local conditions, and no doubt serves the specific needs in those

16 "Water Measurement in Victorian Irrigation Districts—The Dethridge Meter," by I. Meacham, Annual Bulletin 1956, The Internatl. Comm. on Irrig. and Drainage, p. 14.

areas. Many of the devices could serve as well in other areas. They all serve the same final purpose, namely, to control and measure the water to the user. However, to conclude that any one of the devices could be universally adopted would not be judicious.

Many of the devices cited are ingenious. Many utilize natural laws governing flow to accomplish the desired results. All have been produced through thought, work, and research, some more than others. Advantage should be taken of the opportunity to benefit from these developments. Integration of the desirable features of a number of the devices should result in improved present practices and might produce a solution that would be more universally applicable. Current extraordinary demands being placed on the available water resources of the globe may, in the near future, require this improvement.

Journal of the

IRRIGATION AND DRAINAGE DIVISION

Proceedings of the American Society of Civil Engineers

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MONTHLY CONSUMPTIVE USE REQUIREMENTS FOR IRRIGATED CROPS[a]

Closure by Harry F. Blaney

HARRY F. BLANEY,[1] F. ASCE.—The discussers have mentioned certain facts which have added to the limited literature available on the subject of the monthly consumptive use of water.

Mr. C. P. Christopoulos has made an excellent analysis of the application of the Blaney-Criddle (B-C) formula for determining monthly consumptive use, based on practical experience in Greece and other countries. Christopoulos calls attention to the fact that its use is simple, since data on mean monthly temperature (t) and percentage of day-time hours (p), in the formula $u = ktp = kf$ are usually available throughout the world, while factors in more complicated formulas are not usually available. This is the difficulty in using the atmometer method as observations on evaporation from white and black atmometers are only available in a few areas in the world.

Christopoulos' development of the Blaney-Criddle formula for the metric system, as $u = kp\,(8 + 0.45t)$ = monthly use, in millimeters, is a valuable contribution to the literature. While in Turkey, in 1959, the writer learned that the metric formula, $u = 25.4\,\frac{kp\,(1.8t + 32)}{100}$, is being used to determine water requirements for a large irrigation project. In Israel, the (B-C) metric formula, $u = \frac{kp\,(45.7t + 813)}{100}$ = monthly use, is in common use. The writer agrees with Christopoulos that, since irrigation efficiencies may range from 40% to 70%, there is not usually a need for an exact value of consumptive use when estimating irrigation requirements.[2]

The discussion by Mr. Halkias is based primarily on an article that indicates[3] that the atmometer method of estimating monthly use is superior to most other methods commonly used. It makes an unfair comparison of measured monthly consumptive use of water with consumptive use computed by the Blaney-Criddle formula ($U = KF$), because Halkias uses[4] the seasonal coefficients (K) to compute monthly use (u) instead of monthly coefficients (k).

---

[a] March, 1959, by Harry F. Blaney.

[1] Irrigation Engr., Western Soil and Water Mgt. Research Branch, Soil and Water Conservation Research Div., Agric. Research Service, U.S. Dept. of Agric., Los Angeles, Calif.

[2] "Determining Water Requirements in Irrigated Areas from Climatological and Irrigation Data," by Harry F. Blaney and Wayne D. Criddle. Soil Conservation Service, U.S.D.A., SCS-TP-96, August, 1950.

[3] "Determining Water Needs for Crops from Climatic Data," by N. A. Halkias, F. J. Veihmeyer and A. H. Hendrickson. Hilgardia, December, 1955, pp. 207-233.

[4] Discussion of "Monthly Consumptive Use Requirements for Irrigated Crops," by N. A. Halkias. Proceedings, ASCE, Vol. 85, No. IR3, September, 1959, p. 109.

The seasonal coefficient should not be used to compute monthly use. This is admitted in the statement by Halkias,

"The consumptive use coefficient for the entire growing season was used in these calculations, and the computed use rates for May to September period are therefore somewhat low. The use rates in table 3(1) should be calculated from the monthly coefficients, but such data are not available for most of the crops."

However, data on monthly coefficients were available to Halkias, in Table 6 of the writer's paper. Table 1 has been prepared to illustrate how monthly coefficients (k) in Table 6 can be used to compute monthly use by the (B-C) formula, and how close the computed monthly use is to measured use at Davis, California. As indicated in Table 1, if the July monthly coefficient (k) of 1.10 for alfalfa, shown in Table 6 of the writer's paper, had been used by

TABLE 1.—MONTHLY CONSUMPTIVE USE AT DAVIS, CALIF., BY THE BLANEY-CRIDDLE METHOD

	Alfalfa - 1937-38					Tomatoes - 1933-35			
Month	t F^o	p Per-centage	f	k	u Inches	f	k	u Inches	u_1 Inches
April	56.8	8.92	5.07	0.70	3.5				
May	65.4	9.94	6.50	.80	5.2				
June	70.8	9.99	7.07	.90	5.8	7.08	0.45	3.2	3.2
July	75.0	10.13	7.60	1.10	8.4	7.63	.80	6.1	6.2
Aug.	73.0	9.49	6.93	1.00	6.9	7.11	.70	5.0	4.9
Sept.	70.4	8.38	5.90	.80	4.7	5.82	.80	4.7	4.7
Oct.	62.1	7.78	4.83	.70	3.4	4.96	.70	3.5	

Halkias instead of a seasonal coefficient of 0.85, the computed consumptive use at Davis, California by the B-C monthly formula would be 8.3 in for July, or the same as the actual measured use shown in Halkias' tabulation. The tabulation by Halkias includes only water use for four or five warm months. Crops such as alfalfa, cotton, prunes, and walnuts have a seven-month growing season, and it is a misuse of the (B-C) formula to compute monthly consumptive use for hot summer months by seasonal coefficients (K) which are based on a growing season of seven months. Table 1 indicates that monthly water use is needed for the entire growing season for planning irrigation systems.

Mr. Halkias states: "In designing irrigation systems and in planning irrigation programs, it is necessary to determine the water use by crops for the most critical month of the growing season. In this case, the Blaney-Criddle method gives us little information." Table 1 answers this criticism. Apparently, the fact has been overlooked that Table 6 in the writer's paper gives monthly coefficients for the Blaney-Criddle formula for the entire growing season. This formula has been used for many years by state and federal agencies to estimate use of water for irrigation systems throughout the west-

ern United States.[5,6,7,8] In a trip around the world, in 1959, the writer learned that this formula has been used in Greece, Turkey, Israel, Egypt, Pakistan, Afghanistan, India, Japan and Hawaii. Since Halkias' atmometer discussion[4] does not include monthly coefficients for the entire growing season of crops, it does not give complete information needed by irrigation engineers for designing and planning irrigation systems requiring water for seven months of the year. Also, there are only a few places where black and white atmometer records are available.

At various times during the past 30 yr the writer has measured evaporation from white atmometers and it was found that the rates of water use were influenced considerably by climatic factors such as temperature, humidity, dry wind, and precipitation. In 1932, atmometer observations[9] were made at ten different locations and there were extreme variations in the losses from the different atmometers. It is doubtful whether atmometer coefficients developed in a semi-arid climate can be transposed to an arid or humid climate. However, the writer believes that the atmometer method can be standardized and coefficients developed for different climatic conditions. Studies of this problem are being made by the University of California, the Agricultural Research Service, and the California Department of Water Resources.

The discussion by Messrs. Criddle and Higginson calls attention to the fact that consumptive use by crops is influenced by growth and other characteristics, and mentioned some pertinent factors which should be considered when estimating rates of water use. These should be considered in each area. The writer has described these factors in other reports.[2,8] For example, after each alfalfa cutting for feed, the transpiration loss is reduced considerably. Also, the writer found in New Mexico studies that alfalfa will use twice as much water with a water-table at 3 1/2 ft as when the water-table is 5 1/2 ft below the ground surface. The writer agrees with Criddle and Higginson that short-time use rates appear to be an erratic account of many influencing factors.

In designing irrigation systems, particularly farm irrigation sprinkler systems, peak consumptive use rate is important. The carrying capacity of the entire irrigation system is dependent on the peak demand. Based on studies conducted at various locations throughout the western United States, Criddle and others have prepared[10] Table 2 for estimating peak daily rates of consumptive use for the design of irrigation systems when the soil moisture characteristics in the crop root zone are known.

Mr. Munson's discussion mentions several factors that should be considered in the transition of consumptive use from the plot to a project. It is true

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5 "Consumptive Use of Water in the Irrigated Areas of the Upper Colorado River Basin," by Harry F. Blaney and Wayne D. Criddle. Soil Conservation Service, U.S.D.A., April, 1949, pp. 1-49.

6 "Consumptive Use of Water," by Harry F. Blaney. Transactions, ASCE, Vol. 117, 1952, p. 949.

7 "Water Utilization and Requirements of California," California State Water Resources Bd., Bulletin No. 2, June, 1955, pp. 1-227.

8 "Irrigation Requirements of Crops," by Harry F. Blaney. Agricultural Engineering, Vol. 32, No. 12, December, 1951, pp. 665-668.

9 "Indices of Transpiration Opportunity, by C. A. Taylor and Harry F. Blaney, U.S.D.A., 1932-33, (unpublished).

10 "Estimated Water Requirements in Irrigated Areas of Montana," by O. W. Monson, Wayne D. Criddle, and Sterling Davis. Bulletin 494, Montana State College, December, 1953.

that there are several such factors. However, the factors affecting the use of water are in some instances more important than the transition factors. Many factors operate singly or in combination to influence the amounts of water consumed by plants. Their effects are not necessarily constant but may differ with locality and fluctuate from year to year. Some involve the human factors while others are related to the natural influences of the environment. The more important of the natural influences are climate, water supply, soils, and topography. The climatic factors that particularly effect consumptive use are precipitation, temperature, humidity, wind movement and growing season.

Mr. Munson has developed a simple, short method of estimating monthly water consumption. Apparently, the procedure works in areas where a large

TABLE 2.—DETERMINATION OF PEAK CONSUMPTIVE USE OF WATER RATES

Depth of soil moisture to be replaced in root zone each irrigation in inches	Measured or computed peak monthly use—inches					
	3.0	4.0	5.0	6.0	7.0	8.0
	Daily consumptive use design rate, in inches per day					
2	0.14	0.18	0.23	0.27	0.32	0.36
4	.11	.15	.19	.23	.27	.31
6	.10	.14	.17	.21	.24	.17
8	.10	.13	.16	.19	.23	.26

portion of the precipitation occurs during the growing season. However, will it give results in Imperial Valley, California, where the mean annual rainfall is 3 in. or, in many areas in California where rainfall usually does not occur in the months of June, July, and August? This method has possibilities and it is hoped that Munson will prepare a paper describing in more detail the procedure. The method appears to be better adapted to humid and semi-humid areas, where precipitation occurs during the summer months.

Mr. Litz' discussion develops an interesting modification of the Blaney-Criddle equation for computing monthly consumptive use of water by rice from seasonal use data. This method should prove useful for areas where no data are available on monthly consumptive use by rice and some of the other crops. The writer will give Litz' procedure further study.

DRAINAGE OF AGRICULTURAL LANDS USING INTERCEPTOR LINES[a]

Closure by William W. Donnan

WILLIAM W. DONNAN,[1] F. ASCE.—Perhaps the most gratifying thing to happen in connection with presentation of a technical paper is to have discussion engendered. The author is grateful to A. R. Robinson, David K. Todd, Jacob Bear and R. H. Brooks for their pointed and succinct contributions.

One cannot do otherwise than agree with Mr. Robinson's contention that natural field conditions, with all their attendant variables, present a formidable problem in designing an actual interceptor drain. Yet it seems patent that some simplification must be made in order to be able to come to a rational solution.

The large scale model study[2] by Keller and Robinson sheds some additional light on this subject. It is of particular interest to have new information on the shape and position of flow and the nature of the equipotential lines in the vicinity and immediately downslope from the drain device.

The discussion by Todd and Bear is a prime example of the value of exchange of ideas and thinking. The author is pleased to obtain the reference to the early work by Jaeger[3] on the subject of interceptor drains.

In this connection, the correspondence which took place with Glover and others at the United States Bureau of Reclamation (USBR) was reviewed.

The initial manuscript written by the author on the subject of interceptor drains was a mimeographed "white paper," prepared and issued in September, 1953. Copies of this paper were sent to Mr. Lee Dumm, of the USBR, among others, and a lively correspondence resulted. Ideas and theories were exchanged over the next six months, culminating in Glover's mathematical solution. In the fall of 1954, these theories became the subject of a Master's Thesis problem at Colorado A and E College (See Proceedings Paper #2154). I doubt whether any of this group had any knowledge of the work of Jaeger or his derivation.

We have received information from Mr. Marcel Bitoun, M. ASCE, Hyd. Engr., that the "Glover-Jaeger" formula was originally integrated by A. J. Dupuit, himself, and can be found in his last book, "Etudes Theoriques et Pratiques sur le Movement des Eaux a travers les Terrains Permeables," published in 1863. Also, it can be found in a treatise on hydraulics entitled

---

[a] March, 1959, by William W. Donnan.

[1] Agric. Engr., Western Soil and Water Mgt., Research Branch, Agric. Research Service, U.S. Dept. of Agric., Pomona, Calif.

[2] "Laboratory Research on Interceptor Drains," by Jack Keller and A. R. Robinson, Proceedings, ASCE, Vol. 85, No. IR3, September, 1959.

[3] "Engineering Fluid Mechanics," by C. Jaeger, St. Martin's Press, New York, 1957, pp. 1-529.

"Distributions d'Eau," published in 1932, by Mr. George Daries. We are certainly grateful to Mr. Bitoun for contributing this information.

It occurs to the author that the coordinate system for the upslope drawdown as suggested by Todd and Bear is a valid refinement and certainly should be considered in the future.

The author wishes to clear up the statement that Child's inverse relation "does not hold under varying conditions of depth of saturated flow and depth of interception." Child's theory that the shape of the drawdown curve can be analyzed by means of slope does hold. But to mathematically determine the point upslope where the drawdown curve approaches tangency, one must interject the varying conditions of depth of flow and depth of interception.

In the author's original "white paper" it was suggested that the problem of drawdown upslope be resolved by means of slope alone. Then occurred the exchange of ideas and the resulting Glover derivation. To obtain a point of tangency upslope, one cannot ignore depth of flow and depth of interception.

The technique for describing the shape and position of the drawdown curve downslope from the drain device, as advanced by Brooks, is original and intriguing. It would appear that both the mathematical solution as proposed by Brooks and the laboratory tank research carried on by Keller and Robinson[2] seem to refute several statements made by this author.

This author has assumed that the downslope, water table, height is governed by the location of the drain device in the profile. How serious is this error? For open interceptor drains, it is conjectured that the error is negligible. For closed (tile) interceptor drains the error would only become appreciable on excessively steep slopes, in the opinion of this writer. Brooks' contention that the drain device acts as a sink and that it is impossible for water to escape out of the drain device on the downslope side is valid. The original paper by this author consisted partly of a distillation of the theories and research of others. As such, this author refers to an experiment by Childs[4] where an open drain was installed on the impervious layer so as to intercept all the flow downslope, yet some flow did escape out of the drain. Sober reflection points to the fact that this could not occur in a closed tile drain. There would be water by-passing the drain below or above but, as Brooks contends, not out of the drain device.

Again, the author wishes to thank those who have discussed the paper and to applaud their contributions.

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4 "The Water Table, Equipotentials and Streamlines in Drained Land: IV Drainage of Foreign Water," by E. C. Childs, Soil Science, Vol. 62, pp. 183-192.

ECONOMIC EVALUATION OF WATER[a]

Closure by P. H. McGauhey, and Harry Erlich

P. H. McGAUHEY,[1] F. ASCE, and HARRY ERLICH.[2]—The discussions presented are gratifying to the authors of the original paper if for no other reason than that they manifest a healthy spirit of inquiry and a welcome departure from the far too common tendency of ASCE members to permit material to go unchallenged. The discussions also seem to underscore the fact that the subject of water resources is highly "ionized" and controversial, especially at the present time (1960) in California, when major decisions affecting the whole future of the state are under consideration. Because of the charged atmosphere surrounding the topic, a considerable risk is run in discussing water resources development outside the framework of hallowed assumptions and along all but the most conventional lines. Thus, one reader sees in the paper a specific attack on the California water plan, while to another it represents a thinly documented assault on agriculture. Both of these views skirt the central thesis, which is simply this: Let us entertain the possibility that in a state where water use is rising rapidly, climatic conditions restrict the supply, and the cost of development is ever upward; and in a state in which extraordinary population growth is giving rise to numerous problems involving the maintenance of high living standards; the general welfare might be enchanced by policies which give priority to the expansion of areas and uses yielding the maximum growth of California's economy. If this notion is valid, historic western water policies must be reappraised and updated, the wealth-producing potential of proposed state project areas explored, and an appropriate method sought for evaluating the optimum combination of all water uses. Such an approach requires that the water problem be treated within the larger problem of giving purposeful direction to the future pattern of California's overall development.

Some limitations of the paper derive from the fact that it is condensed from a more comprehensive report[3] in which emphasis is placed upon the wide scope of interrelated effects accompanied by water resource development. Because of the multiplicity of these interactions the justification for development decisions may not be reduced to single quantitative answers. However, further investigation and reflection in connection with a follow-up study, now (1960) in preparation, reinforce the conviction that the criteria for

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[a] June, 1959, by P. H. McGauhey and Harry Erlich.

[1] Dir., Sanitary Engrg. Research Lab., Univ. of California, Berkeley, Calif.

[2] Public Administration Analyst, Sanitary Engrg. Research Lab., Univ. of California, Berkeley, Calif.

[3] "Economic Evaluation of Water, Part I, A Search for Criteria," Water Resources Contribution No. 13, Univ. of California, Sanitary Engrg. Research Lab., Berkeley, Calif.

project selection in present use are unrelated to the goal of giving priority to productivity.

To attempt to debate all the points made by the discussors is beyond the scope of this closure, but a few merit further comment. Mr. Lewis contends that only in rare cases has there been actual competition between irrigation and industry. Several examples might be cited in California (such as, the recent $2 million settlement between highly industrialized East Bay Municipal Utility District and largely agricultural Amador and Calaveras counties over Mokelumne River water), but more important is the rationale for future adjustments as the state becomes more fully developed and new forms of water use vie with time-honored legal priorities and distribution concepts.

Mr. Lewis also asserts that it is unwarranted to hold that water committed to irrigation is irretrievable. Commitment to irrigation may take several forms, including selection of distribution routes, repayment policies, and appropriation priorities. Once a route is adopted and concrete poured, commitment to irrigation is certainly irretrievable, even though potential municipal and industrial uses lie outside the service area. Moreover, a state repayment policy designed primarily to provide low-priced irrigation water with distribution geared to ability to pay, rather than to wealth-producing capacity, may well make permanent consignments of heavy water allotments to low return usage. These factors deter pride changes and render this form of commitment virtually immutable by competition from federally subsidized water, and gound water pumped at energy costs only, as well as by political considerations. Finally, statutory priorities to the use of water in California give no preference to industrial use but place irrigation usage second only to domestic. Should alternative allocation to irrigation or industrial use be arbitrated by administrative discretion, commitment to irrigation would probably be reversed only through costly litigation aimed at including industrial use within the preferred municipal category.

On the question of land capability Mr. Lewis states that surely 93 to 99.5% of California's land are not third class or worse, and he charges that the possibility of irrigating good land, that are presently without water, has been disregarded. California's 100,000,000 acres make it a giant among states, but relative land capability percentages become meaningful when it is recognized that mountains, foothills and vast deserts with poor soil texture comprise an immense proportion of the state. Perhaps 2,250,000 acres of high capability land are without water but much of it is scattered and if it is to be served, the way will be opened for deliveries to unproductive marginal lands en route. There are varying standards for determining land quality, but if only 2,250,000 acres of good land are without water, this amount represents 2.2% of the total state area. Together with the 1.6% in Class I and the 5.1% in Class II, therefore, 91.9% are third class or worse. Even so, the remaining 8,900,000 acres of fertile land is a sizable amount. However, it is significant that about 7,000,000 acres (about one-fourth of all that in the nation) are already under irrigation so that approximately two-thirds of the state's arable land is irrigable from existing facilities. Unfortunately, much of this good land is rapidly being overrun by urban growth, causing displacement of agriculture to more marginal lands.

Indulging in analogies, Mr. Lewis observes that the value of coal as a fuel cannot be compared with its value as a chemical derivative. The point here is that differences in value serve to demonstrate the need for using scarce re-

sources to produce high value commodities which add to the general welfare as against subsidizing the production of low-value goods whose economic yields do not warrant public investment. In a state in which water is the limiting factor to economic growth, long-range allocation under conditions of full utilization must be considered paramount.

In his allusion to the interrelationship between urban and agricultural growth, Mr. Thomas has pinpointed the core of the problem. If economic growth is the desideratum of public policies, continuing analysis of the interdependent relationship of its various economic sectors, that might then be translated into physical master plans prepared in accordance with the growth potentialities of California's component watersheds, would provide the soundest basis for priorities on area development, water allocation and power production. Unfortunately, there has been little investigation of the way segments of the state's economy interact and wide gaps exist in physical master plans through which growth might be guided along sound lines. In a forthcoming study, these matters are given attention and a rather detailed quantification of how the separate parts of California's economy interact in an economic whole will be presented. Elaboration of the contents is inappropriate here, but it should be said that the evidence runs counter to the popular tendency to overstress the pump priming effects of agricultural expansion.

ANNUAL DROUGHTS[a]

Discussion by N. E. Minshall and D. A. Woolhiser

N. E. MINSHALL,[1] M. ASCE and D. A. WOOLHISER,[2] A.M. ASCE.—Mr. Boyer has presented methods by which annual droughts can be evaluated. From an analysis of average yield of corn and average growing season temperature and precipitation for Iowa, he concludes that, except for three extremely dry years, there is no apparent correlation between growing season precipitation or temperature and yield of corn. He states correctly that corn yields are affected by many other factors including planting time, management practices, and fertility levels.

The author has defined a drought as: "a period of lack of moisture, during the crop growing season, sufficiently long to damage or destroy a crop." He also states that studies of droughts in humid regions require the examination of monthly precipitation records, yet uses in his analysis a growing season of several months. From a comparison of the growing season precipitation with the source data, the writers conclude that the author has taken April through September as the growing season.

The writers believe there are three possible explanations for the author's apparent failure to obtain a correlation between corn yields and temperature or precipitation: (1) because of low plant populations, low fertility levels, poor management practices, and lack of improved varieties, during the early years, moisture may not have been the limiting factor in corn production, (2) use of the growing season precipitation rather than some shorter period when the moisture requirement of the crop is at or near maximum, and (3) state-wide averages should not have been used, in this evaluation, as they tend to obscure rather large variations in soil type, management practices, and distribution of precipitation.

From studies on the effect of irrigation on corn yields from the sandy soils of Central Wisconsin,[3] "the most critical period, from the standpoint of available water is from tasseling to about 30 days after pollination. A moisture shortage at this time will reduce yields." This critical period, in Central Wisconsin, is from about mid-July to mid-August and perhaps somewhat longer in Iowa. Any study of the effect of precipitation on corn yields should, therefore, be limited to the months of July and August. Records of precipitation and runoff have been collected, by the Agricultural Research Service, on

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[a] Sept. 1959, by M. C. Boyer.

[1] Hydr. Engr., Watershed Technology Research Branch, Soil and Water Conservation Division, Agricultural Research Service, Madison, Wis.

[2] Hydr. Engr., Watershed Tech. Research Branch, Soil and Water Conservation Div., Agric. Research Service, Madison, Wis.

[3] "Irrigated Corn in Central Wisconsin," Bulletin 541, Wisconsin Agric. Experiment Sta., October, 1959.

four small watersheds near Fennimore, in southwestern Wisconsin since July, 1938. Table 1 shows the precipitation each year for an April to September growing season and the July, August critical periods and the departures from normal. Table 1 shows only 7 yr out of 21 yr when the April through September precipitation was below average, but 12 yr when July and August rainfall was below average. Table 1 also shows that 6 of the years with July and August below normal had April through September amounts well above normal. This study of rainfall amounts and distribution during July and August indicates that corn yields were probably limited by lack of moisture in 9 out of 21 yr. Corn yields under a high level of fertility, obtained on one field from 1952

TABLE 1.—SUMMER PRECIPITATION AND CORN YIELDS AT FENNIMORE, WISC.

Year	Rainfall, in Inches				
	April thru September	Departure from Normal	July thru August	Departure from Normal	Corn Yield, High Fertility, Bushels per Acre
Normal	19.82		7.82		
1939	16.24	- 3.58	5.85	- 1.97	
1940	28.60	8.78	18.27	10.45	
1941	22.03	2.21	2.91	- 4.91	
1942	25.01	5.19	5.68	- 2.14	
1943	24.41	4.59	10.95	3.23	
1944	27.22	7.40	8.77	0.95	
1945	28.56	8.74	6.05	- 1.77	
1946	19.66	- 0.16	5.30	- 2.52	
1947	27.31	7.49	3.78	- 4.04	
1948	14.97	- 4.85	4.63	- 3.19	
1949	18.78	- 1.04	4.58	- 3.24	
1950	30.94	11.12	13.53	5.71	
1951	32.24	12.42	15.97	8.15	
1952	19.50	- 0.32	9.43	1.61	155
1953	18.54	- 1.28	8.30	0.48	139
1954	31.16	11.34	6.05	- 1.77	128
1955	16.02	3.80	2.80	- 5.02	50
1956	24.77	4.95	9.40	1.58	120
1957	21.85	2.03	4.26	- 3.56	
1958	15.97	- 3.85	7.07	- 0.75	125
1959	26.05	6.23	9.03	1.21	

to 1958 except for 1957, varied from a low of 50 bushels per acre in 1955 to 155 bushels in 1952. No yield data are included for 1959 because the crop was severely damaged by blight. The yields during 5 out of 6 yr shown are well above 100 bushels per acre. The yield of 125 bushels per acre in 1958, a year of deficient rainfall, was due to a very favorable distribution during the critical period.

The Iowa Climatological Data reports the average precipitation for nine regions of the state representing approximately equal areas. Table 2 gives the maximum and minimum regional July and August and statewide average precipitation in Iowa for the years 1938 through 1948. This shows that only 1941 and 1947 were seriously deficient on a state wide basis, yet regional

TABLE 2.—STATE AVERAGE AND REGIONAL MAXIMUM AND MINIMUM OF JULY AND AUGUST RAINFALL FOR IOWA (1938-1948), IN INCHES

Year	July			August			Sum of July and August Average Rainfall
	Regional minimum	State average	Regional maximum	Regional minimum	State average	Regional maximum	
1938	2.33	4.24	5.97	1.60	3.82	6.90	8.06
1939	2.11	3.15	3.96	3.00	4.72	6.90	7.87
1940	2.78	4.57	6.98	3.92	6.44	8.32	11.01
1941	1.57	2.24	3.36	1.39	1.94	2.67	4.18
1942	3.16	4.89	6.44	1.79	3.17	4.05	8.06
1943	3.14	4.56	5.89	3.23	5.07	6.83	9.63
1944	2.36	3.73	6.05	4.17	5.88	7.38	9.61
1945	1.08	2.96	4.68	2.06	3.43	5.30	6.39
1946	1.41	2.45	4.10	2.14	3.55	5.80	6.00
1947	0.75	1.72	3.47	0.90	1.49	2.15	3.21
1948	2.03	4.14	6.08	1.21	2.54	3.24	6.68
Average		3.51			3.82		7.34
Average 1873 to 1948		3.64			3.58		7.22

TABLE 3.—JULY-AUGUST RAINFALL AND CORN YIELDS FROM THE BEST IRRIGATED AND NON-IRRIGATED PLOTS ON TWO DIFFERENT IOWA SOILS

Year	Conesville (Thurman Loamy Sand)[a]				Ankeny (Nicollet Loam)[b]			
	Rainfall, in inches	Yield, in Bushels per Acre			Rainfall, in inches	Yield, in Bushels per Acre		
		Non-irrigated	Irrigated	Difference due to irrigation		Non-irrigated	Irrigated	Difference due to irrigation
1951	9.92	85.0	75.6	-9.4				
1952	6.55	95.4	130.8	35.4				
1953	6.16	63.8	113.7	49.9				
1954	9.43	89.3	113.7	24.4	11.48	73.3	87.8	14.5
1955	3.24	38.8	110.2	71.4	5.46	87.2	114.8	27.6
Normal	6.18				7.49			
Average		74.5	108.8	34.3		80.2	101.3	21.1

[a] Water holding capacity 0.5 in. per ft. [b] Water holding capacity 1.8 to 2 in. per ft.

minimums for July were less than 60% of the long-time average for 6 out of 11 yr, and August had regional minimums for 5 of 11 yr less than 50% of average. At least one region in the state had below-average July rainfall every year and below average for August for 9 out of the 11 yr. In the monthly weather summaries of Climatological Data, during this period, mention is made of moisture deficiencies in some region of the state for every year except 1942 and 1944.

Conclusions regarding the value of irrigation should be based on a comparison of yields, for several years, from irrigated and non-irrigated fields under good management practices and on various soil types. Experimental data on the effect of irrigation on corn yields for the past few years are available from the State Agricultural Experiment Stations.

Experiments on irrigated and non-irrigated corn were conducted by the Wisconsin Agricultural Experiment Station[3] on a sandy soil in Central Wisconsin from 1954 through 1958. The results show that, for this particular soil type and climatic condition, the non-irrigated corn yielded an average of 48 bushels per acre as compared with 126.9 bushels for the irrigated corn both under high fertility levels. July precipitation was above normal each year but August was deficient in 3 out of the 5 yr.

Experiments on response of corn yields to irrigation are also being carried on by the Iowa Agricultural Experiment Station.[4] Results from two of these studies, given in Table 3, show that for the loamy sand at Conesville, yields were increased in years of average precipitation (1952-1953) by 35 and 50 bushels per acre.

Maximum average yields shown for the State of Iowa are 60 bushels per acre; but the material presented here, by the writers, indicates a potential production under high fertility, good management practices, and ample moisture at the critical period in excess of 100 bushels on some widely different soil types. Yields of non-irrigated fields in years of good rainfall should not be used to evaluate the possible additional crop returns which could result from application of supplemental irrigation at a critical period. The use of state-wide averages of both precipitation and yields serves to conceal variations which may have been due to an excess or deficiency of moisture at a particular location. Although corn yields may show a response to irrigation, experimental data and long-term rainfall records must be utilized in an economic analysis to determine if the added returns justify the additional expense of irrigation.

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4 "Research on Irrigation of Corn and Soybeans at Conesville and Ankeny, Iowa 1951 to 1955," Research Bulletin 458, Agric. and Home Economics Experiment Sta., March, 1958.

LABORATORY RESEARCH ON INTERCEPTOR DRAINS[a]

Discussion by William F. Long, William W. Donnan, Herman Bouwer, Jan van Schilfgaarde, R. William Nelson, John G. Sutton

WILLIAM F. LONG,[1] M. ASCE.—The model study reported on should be of much interest and value to engineers confronted with problems in designing interceptor type drains. This study is an outstanding effort to gather data on the slope and configuration of draw-down curves to interception type drains. It has confirmed several theories about the slope of these draw-down curves.

There is considerable information available on the slope of draw-down curves to parallel-type relief drains; conversely, there is very little information on interception drains. This is due to the fact that a large percentage of the subsurface drains in the United States are relief-type drains and emphasis has been placed on research of relief-type drains. Interceptor-type subsurface drains are relatively new in the field of drainage. There is much research yet to be performed in this specific field. The authors and the research organization for which they work are to be commended for their efforts in this field which is relatively unknown.

In the introduction to this paper the authors state "Interception of ground water flowing laterally from a source which may be outside the affected area is the common problem." This describes a situation where all accretion to the drain is foreign to the immediate area being protected. In the writer's opinion the common situation is one where we have this accretion, from an outside source as discussed above, plus local accretion. The local accretion in the immediate area is deep percolation from precipitation, irrigation, or both, as the case may be. It is unfortunate that this model study did not include provision for evaluating the effect of this local accretion which is usually present under actual field conditions.

Information gained from evaluating a number of interception drains over a wide range of field conditions agrees with the general findings and conclusions of the authors. Draw-down curves to interception drains are relatively steep and, consequently, the affected area above interception drains is relatively small. For this reason interception drains are located near the upper edge of wet areas. The greatest effect of interception drains is usually to the area below the drain. It is hoped that future model studies will be planned to determine the position, slope, and configuration of water-table levels below interception drains. These should be planned and devised to evaluate the effect of all accretion including percolation losses from precipitation and/or irrigation.

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[a] September, 1959, by Jack Keller and A. R. Robinson.

[1] Civ. Engr. Soil Conservation Service, Lincoln, Nebr.

WILLIAM W. DONNAN,[2] F. ASCE.—This paper is an important contribution to the literature on interceptor drains. The studies they made with the large scale model substantiate, at least in part, previously developed analytical relationships.

This writer has followed the work of Messrs. Keller and Robinson with extreme interest. Having assembled and developed some theories on interceptor drains,[3] the question arose as to how to check on the accuracy of these theories. Field investigations are often inconclusive since they are usually clouded by unknown and non-measurable variables.

After seeing a large tilting flume in the Hydraulics Laboratory at Colorado State University, Fort Collins, Colorado, the idea was formulated to use such a device as a sand tank to test the interceptor drain theories. The tilting flume could be set on various slopes and thus check on the slope variable in interception.

The existing flume at Fort Collins was not available for use so a new 70-ft flume was built. It may be of interest to note that at the conclusion of the interceptor drain research, a wall was knocked out of the Hydraulics Laboratory and the two tilting flumes were joined together to create one of the longest indoor tilting flumes in the world for use in hydraulic research work.

In a model as large as this 70-ft long tilting flume, the problem of getting uniformity of the porous media and uniformity of compaction of the material presents difficulties. Uniform compaction was derived by using a pneumatic vibrator of the type used in pouring concrete.

It seems apparent that the success of the Keller and Robinson project with this large model should give impetus to more research on drainage problems with large tilting tanks or flumes. More work needs to be carried out on flow into drains and on optimum location of the interceptor drain with respect to the reservoir, canal or other source of seepage. In addition, careful studies should be made of the flow phenomenon adjacent to and immediately down slope from the interceptor drain.

HERMAN BOUWER.[4]—The authors report on a sand-model study of steady, two-dimensional flow systems in a porous medium. These flow systems, however, are also suitable for analysis by analog such as resistance networks or others. It would be interesting to compare the results in this paper with data obtained by analog to determine, for instance, whether solution by analog might not be a more feasible approach for studying problems of the type discussed in the paper. A resistance network analog would be especially adapted in this case, since it affords simultaneous solution of the flow above as well as below the water table and water-table shapes are found as products of the analysis.[5]

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[2] Agric. Engr., Western Soil and Water Mgt., Research Branch, Agric. Research Service, U.S. Dept. of Agric., Pomona, Calif.

[3] "Drainage of Agricultural Lands Using Interceptor Lines," by W. W. Donnan, Proceedings, ASCE, March, 1959.

[4] Senior Agric. Engr., Southwest Water Conservation Lab., Western Soil and Water Mgt. Research Branch, Soil and Water Conservation Research Div., Agric. Research Service, U.S. Dept. of Agric., Tempe, Ariz.

[5] "A Unifying Numerical Solution for Two-Dimensional Steady Flow Systems in Porous Media with an Electrical Resistance Network," by Herman Bouwer and W. C. Little, Soil Sci. Soc. Amer., Vol. 23, 1959, pp. 91-96.

The authors worked with a rather course sand with a "capillary rise" of 1.5 in. This may justify their assumption of no bypass flow above the drains. In the light of presently available data, however, the order of magnitude of the height of capillary fringes above water tables in field soils may be 1 ft, less for coarse soils, more for structureless clay soils. For shallow flow systems such as in this study, therefore, the capillary fringe may be of sufficient height to render the flow above the water table of considerable importance. Water may pass over the drains as tension flow in the capillary fringe and continue its seepage downhill. To also intercept the flow above the water table, it would be necessary to use an open ditch as interceptor, or, if tile drains are desired to backfill the trench with a coarse material or to line it with an impermeable membrane.

JAN VAN SCHILFGAARDE.[6]—The authors present some excellent data on the flow of water through gravel towards interceptor drains together with parts of a theoretical solution. They show that theory and experimental data are in close agreement. However, they fail to make full use of this agreement when they do not show that the theory they present is fully adequate to solve the problems that are posed, both as to flux and shape. The authors' Eq. 10 apparently is a solution of the differential equation

$$q_t = Ky\left(\frac{dy}{dx} + s\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

with the substitution $H = q_t/Ks$. Here H is not used with the same meaning as elsewhere in the paper. This H is the thickness of the aquifer where $dy/dx = 0$, that is, where $x = \infty$, and not the height of the aquifer at $x = L$. The authors resolve this dilemma by introducing $H' = q_t/Ks$ in Eq. 11, so that H may be reserved for the head water depth. It should be noted that the "adjustment" of Eq. 10 by the introduction of H', as proposed by the authors, implies a misinterpretation of the origin of Eq. 10. Eq. 11 results directly from a solution of the writer's Eq. 1 when one integrates between the limits 0 to x on x and h to y on y.

Since $H' = q_t/Ks$, the value of H', or of the total flow through the aquifer, q_t, may be determined from Eq. 11 by the substitution $x = L$ and $y = H$. Rearranging into dimensionless groups, this substitution yields

$$\frac{H}{Ls} - \frac{h}{Ls} + 1 = \frac{q_t}{KLs^2} \ln \frac{q_t/KLs^2 - h/Ls}{q_t/KLs^2 - H/Ls} \quad \ldots\ldots\ldots \quad (2)$$

Thus, it is possible to calculate, by means of the theory, the total flux from the parameters of the problem, just as Fig. 3 enables such determination from the experimental data. The writer's Fig. 1 eliminates the need for solving his Eq. 2 by trial and error and provides a graphical solution which parallels the authors' Fig. 3.

In case $s = 0$, a solution of the same differential equation results in the authors' Eq. 17 with the exponent $n = 1$. An intermediate result is

$$q_d/K = q_t/K = \left(H^2 - h^2\right)/2L \quad \ldots\ldots\ldots\ldots \quad (3)$$

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[6] Assoc. Prof. of Agric. Engrg., N.C. State College; and Drainage Engr., Soil and Water Conservation Research Div., Agric. Research Service, U.S.D.A., Raleigh, N.C.

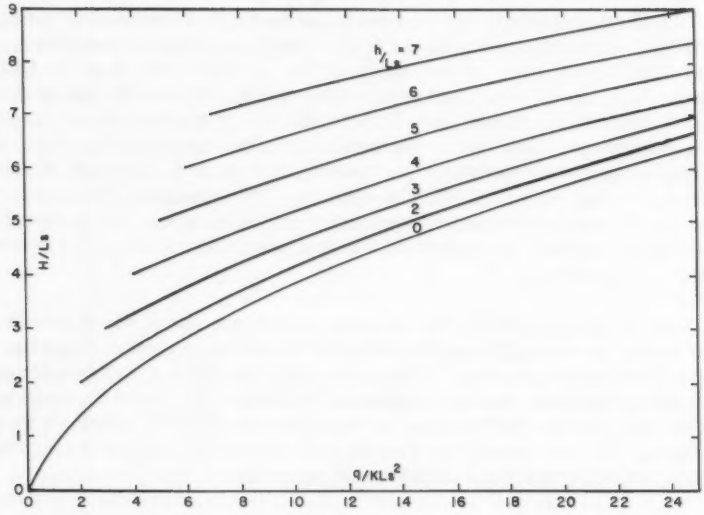

FIG. 1.—GRAPHICAL SOLUTION OF WRITER'S EQUATION 2

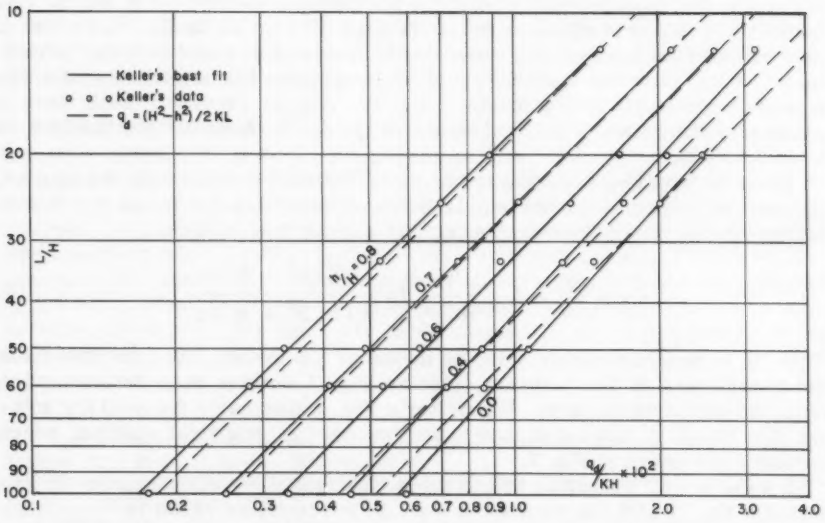

FIG. 2.—THEORETICAL CURVES SUPERPOSED ON AUTHORS' FIG. 6

The writer's Fig. 2 is a copy of the authors' Fig. 6 with a plot of Eq. 3 superimposed on it. Thus the agreement between theory and experiment, claimed by the authors for the shape analysis, can again be extended to the flux analysis. To illustrate, the author's first example gives $H/Ls = 5$ and $h/Ls = 2$; the writer's Fig. 1 yields $q_t/KLs^2 = 14.5$. Hence, with $K = 0.0001$ fps, $q_t = 0.000029$ cfs; $q_b = Khs = 0.000004$ cfs; $q_d = q_t - q_b = 0.000025$ cfs. This compares with $q_d = 0.000026$ cfs as found by the authors. Their second example gives $H/Ls = 1$, $h/Ls = 0.5$, and, from Fig. 1, $q_t/KLs^2 = 1.2$; thus $q_t/Ks = 12$. This compares with the authors' $H' = 11.9$.

The conclusion that may be drawn from the above is that the authors' data substantiate the assumptions underlying their theory and that, therefore, one should not hestiate to use the theory freely in the solution of problems within the limitations of this study. This conclusion seems more generalized and of greater practical significance than the authors' suggestion that the experimental data per se, may be used for prediction purposes.

One important limitation of the study should be brought out. The choice of the very coarse material in the model is consistent with the assumption in the theory that the water table bounds the flow region, but it ignores the often significant portion of the total flow above the water table in field situations.

R. WILLIAM NELSON.[7]—Mr. Keller and Mr. Robinson are to be complimented on their experimental examination of (1) the upstream water table shape, and (2) the drain discharge, for steady flow down a slope and into an interceptor type drain. The extension of Glover's equation through the introduction of H' is commendable because in practice a source of water at a finite distance is often found.

Through the authors' verification of Glover's equation, a good approximation for some phases of a flow system, has been obtained for the exact but more complicated Laplace equation through use of the Dupuit-Forchheimer Assumptions. Nevertheless, assumptions are contained in the expression, and inaccurate predictions may result in some phases of the flow problem. Careful study of the desirable and limiting features of Glover's equation will provide the judgment which is so necessary for realistic use of an approximation.

In analyzing the assumptions it will be helpful to state the interceptor drainage boundary value problem studied by Messrs. Keller and Robinson. From the basic equation and boundary conditions, a complete set of dimensionless variables are specified through inspectional analysis. The desirable features of inspectional analysis over dimensional analysis are nicely illustrated in formulating the interceptor drain problem as presented in the next section.

BOUNDARY VALUE PROBLEM ASSOCIATED WITH THE INTERCEPTOR DRAIN

The basic equation and boundary conditions for the interceptor drain are needed in order to discuss the assumptions contained in the relationships

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[7] Formerly Agric. Engr., Western Soil and Water Mgt. Research Branch, Soil and Water Conservation Research Div., Agric. Research Service, U.S. Dept. of Agric., Fort Collins, Colo., presently Engr., Geochemical and Geophysical Research, Chem. Effluents Tech., Hanford Labs. Operation, General Electric Co., Richland, Wash.

studied by Keller and Robinson. Through such an analysis, it will be possible to strengthen their results and draw certain conclusions about the downstream water table.

The same assumptions used by Glover, with regard to soil of homogeneous and isotropic permeability and steady flow down the slope, will be assumed. The nomenclature used is essentially Keller's with the flow system schema shown in Fig. 1. The piezometric head or potential function Φ is

$$\Phi = \frac{p}{\rho g} + z \cos \theta - x \sin \theta \quad \ldots\ldots\ldots\ldots \quad (1)$$

From Darcy's Law the velocity components are

$$v_x = -K \frac{\partial \Phi}{\partial x} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$v_z = -K \frac{\partial \Phi}{\partial z} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

in which $\frac{p}{\rho g}$ is the pressure head, Φ denotes the piezometric head or potential function which is a function of x and z, ρ is the density, g refers to the gravi-

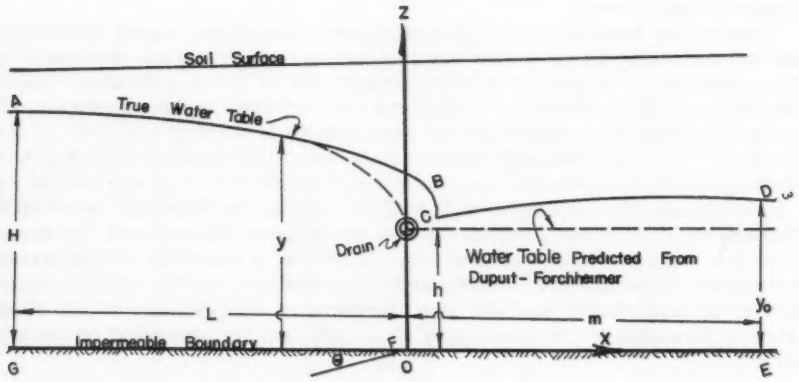

FIG. 1.—SCHEMA OF INTERCEPTER DRAIN

tational scalar, v_x is the velocity in x direction, v_z is the velocity in z direction, K denotes the saturated hydraulic conductivity or permeability, y is the distance to the water table above the impermeable layer, the value of y is only defined along the water table), and the other symbols are as shown in Fig. 1.

Since flow in planes normal to the drain shown in Fig. 1 are identical, then only flow in the x-z plane need be considered whereupon combining Darcy's Law with continuity gives the general equation.

$$\text{The Basic Equation, } \frac{\partial^2 \Phi}{\partial x^2} + \frac{\partial^2 \Phi}{\partial x^2} = 0 \quad \ldots\ldots\ldots\ldots \quad (4)$$

is the equation which must be satisfied by Φ in order for it to be a solution.

The boundary value problem can be expressed more efficiently in dimensionless variables and parameters. Using the boundary parameters shown in Fig. 1 as scaling factors, let $u = \frac{x}{L}$, $w = \frac{z}{L}$, and $\phi = \frac{\Phi}{H}$. Substituting these values into Eq. 1 results in the dimensionless potential ϕ being,

$$\phi = \frac{p/\rho g}{H} + \frac{L}{H} w \cos\theta - \frac{L}{H} u \sin\theta \quad \ldots\ldots\ldots\ldots \quad (5)$$

Eq. 4 reduces to dimensionless form upon changing the variables in accordance with the previous listing

$$\frac{\partial^2 \phi}{\partial u^2} + \frac{\partial^2 \phi}{\partial w^2} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

The boundary conditions are

$$\phi(-1, w) = \frac{L}{H} \sin\theta + \cos\theta \quad \ldots\ldots\ldots\ldots\ldots \quad (7)$$

$$\phi\left(0, \frac{h}{L}\right) = \frac{h}{H} \cos\theta \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

$$\frac{\partial \phi(u, 0)}{\partial w} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

$$\phi\left(\frac{m}{L}, w\right) = \frac{y_o}{H} \cos\theta - \frac{m}{H} \sin\theta \quad \ldots\ldots\ldots\ldots \quad (10)$$

$$\phi\left(u, \frac{y}{L}\right) = \frac{y}{H} \cos\theta - \frac{L}{H} \sin\theta\, u \quad \ldots\ldots\ldots\ldots \quad (11)$$

and

$$\frac{\partial\left[\phi\left(u, \frac{y}{L}\right)\right]}{\partial n} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

with n being normal to the water table.

$$\frac{y_o}{L} = \frac{H}{L} - \frac{Q_d}{L K \sin\theta} \quad \ldots\ldots\ldots\ldots\ldots \quad (13)$$

The only simplifying boundary assumption made is in Eq. 8 in which the drain has been considered as a point sink rather than a drain of finite radius r. This assumption is justified as pointed out by Keller and Robinson.

A set of dimensionless parameters which completely describe the flow system (ϕ as a function, F) are immediately obtained from inspection of Eq. 6 through 13, that is

$$\phi\,(u,\ w) = F\left[\frac{L}{H},\ \theta,\ \frac{h}{H},\ \frac{y_o}{H},\ \frac{m}{H},\ \frac{y}{H}\right] \quad \ldots\ldots\ldots\ldots (14)$$

Through the inspectional procedure we are assumed that the resulting set of dimensionless ratios (Eq. 14) completely describes the system.

Upon comparison of the dimensionless variables in Eq. 14 with those of Keller, m/H and y_o/H are not in the latter's analysis. Yet in the experimental procedure the investigators had to arbitrarily set these ratios with y_o/H being made equal to h/H at some m/H. With y_o/H being arbitrarily set at values of m/H, the usual check on completeness in the dimensional analysis could not function. In other words, the consistency of data when plotted in terms of the dimensionless variable does not assure in this case completeness with respect to these two variables since the experiment did not allow y_o/H to vary. Accordingly there may be problems in the experimental system used from having held the two ratios essentially constant.

The flume experiment of Keller and Robinson could be thought of as an analog computer which in effect solved the basic equation meeting all of the boundary conditions except Eq. 13. This condition on y_o could have been found by successive adjustments through setting y_o to some reasonable value, then measure Q_d, the steady drain discharge, and compute what y_o should have been from Eq. 13. If the calculated value of y_o was different from the set value, readjustment could be made until the calculated y_o was the same as that in the tail box. Once the calculated and set values agree then the basic equation and all of the boundary conditions are satisfied.

Keller's experimental procedure of setting y_o equal to h for some m/H implicitly assumes the downstream water table is a straight line parallel to the impermeable layer and passing through the drain. The significance of the unexamined ratios really reduce to how closely the Dupuit-Forchheimer Assumptions describe the actual flow system. If they are a rather good approximation for some phases of the flow system, then the arbitrary setting of y_o equal to h may not have affected those phases of Keller's study.

DUPUIT COMPARED TO LAPLACIAN FORMULATION

In the last section the rigorous Laplacian formulation for the interceptor drain was obtained. To this time the problem has defied exact analytical solution.[8] However, several things can be learned from the formulation without the complete solution. These partial results will provide a basis for evalua-

[8] The author has pursued such an analytical solution in considerable detail through conformal mapping of the derivative of the complex potential onto a half plane, on which the Hodograph plane was previously mapped. An integration involving the angle θ required for a Schwarz-Christoffel transformation has to date prevented solution by such a method.

tion of the Dupuit-Forchheimer Assumptions thereby suggesting the significance of the downstream parameters which were not considered.

The general downstream water table shape can be rigorously established by using the results of the previous section in the complex velocity or Hodograph plane. Brooks presented[9] the results establishing the downstream water table shape in his discussion of Donnan's paper,[10] so detailed discussion here is unnecessary. Briefly it was found, with Brooks qualitatively substantiating this data with a sand tank model, that: 1) Immediately downstream of the drain there is a stagnation point (point C in Fig. 1). 2) The water table never intersects the drain. 3) The downstream water table gradually rises with increasing x, i.e., between C and D the water table has a positive slope ($dy/dx > 0$). Accordingly, the actual downstream water table shape for the interceptor drain is as shown schematically in Fig. 1. For comparison, the

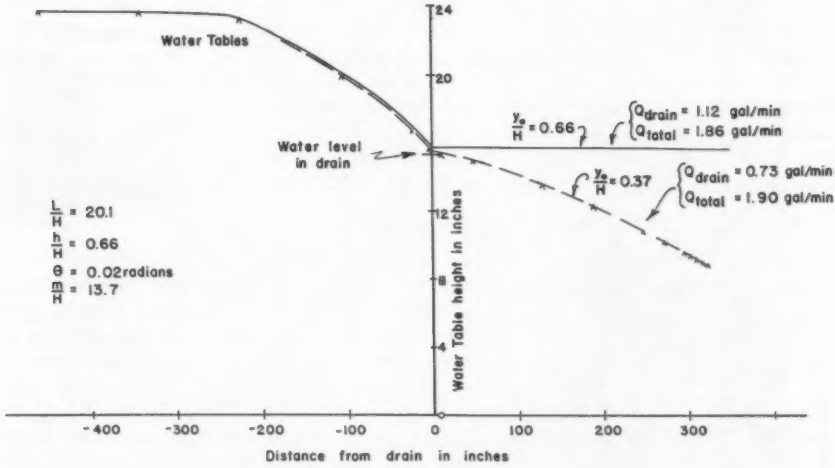

FIG. 2.—WATER TABLE SHAPE

dashed lines representing the predicted water table shape based upon the Dupuit-Forchheimer Assumptions are shown in Fig. 1.

In the experimental work of Keller, y_o was always set smaller than it should have been. Accordingly, the upstream water table would be lowered slightly near the drain with an ever-decreasing amount at greater distances upslope from the drain. Perhaps more significantly a smaller y_o would cause the drain to intercept less of the water than might otherwise have been removed. The change in drain outflow would be expected to be a large error in comparison with the upstream water table difference which probably is quite insignificant.

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[9] Discussion of "Drainage of Agricultural Lands Using Interceptor Drains," by R. H. Brooks. Submitted for publication to Proceedings, ASCE.

[10] "Drainage of Agricultural Lands Using Interceptor Drains," by W. W. Donnan, Amer. Soc. of Civil Engr. Proc. Paper 1964, IR-1, March 1959.

Keller and Robinson present data that shows the changes of drain discharge and upstream water table shape with the downstream heights y_o/H for $m/H = 13.7$. These results shown in Fig. 2 indicate only a slight effect on the upstream water table shape by changing y_o. However, there is considerable change in the tile discharge. Likely the difference between the true y_o and that used (h) was usually a third or fourth of the change shown in Fig. 2. Unfortunately, the true difference isn't known so no definite conclusion can be made regarding the probable bias in the observed drain discharges.

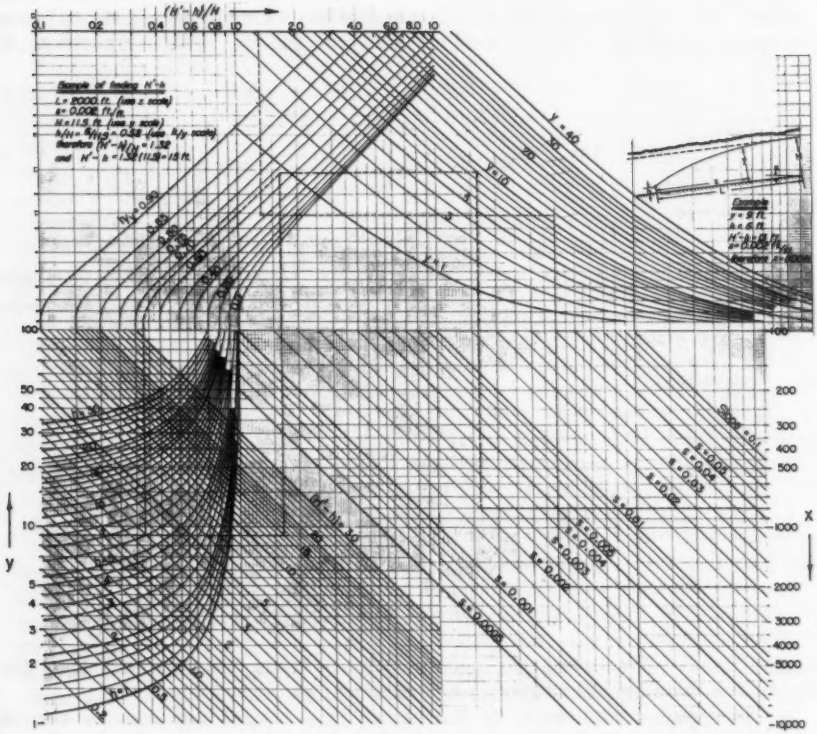

FIG. 3

From the above discussion and results shown in Fig. 2, the Keller-Robinson conclusion—that the upstream water table is adequately described by the Glover equation—is very much justified. The same certainty is not justified with regard to the predicted tile discharge although it may be correct. Certainly it is the best available estimate of discharge and probably is not in error by more than 15%.

COMPUTATIONAL AIDS FOR GLOVER'S EQUATION

Experience with Glover's equation in a design method[11] for hetergeneous soils indicated an easy method of calculating the drawdown curve would be helpful. Accordingly, Mr. Donald Miles devised a series of curves, Fig. 3, incorporating the results of Keller and Robinson, which allows rapid graphical solution of Glover's equation. The value of H' can also be found through use of the progressive graphs.

More description of the examples given in Fig. 3 may be helpful. The known conditions are: H = 11.5 ft, h = 6 ft, L = 2,000 ft, and s = 0.002 ft per ft. The value for H'-h must be found in order to get the drawdown curve. This is accomplished in the example in Fig. 3 by entering at 2,000 on the x scale (L and H are just a limiting pair of x and y values) and following the dashed lines to get H'-h/H. This gives H'-h as 15 for later use in the upper right hand example.

To get the complete drawdown curve it is easiest to assume a value of y and calculate the associated x. Assuming y = 9 (see right hand example, Fig. 3) and entering the left hand y scale move horizontally to h = 6, hence upward and following the curved dashed line, meanwhile continuing horizontally along y = 9 to (H'-h) = 15, then upward to the intersection with the earlier curved dashed line, thence horizontally to y = 9, then down to s = 0.002 and horizontally thereby finding x = 800 ft. By successively assuming values for y and finding the x in a like manner, the entire drawdown curve is easily and quickly found.

JOHN G. SUTTON,[12] F. ASCE.—This paper will be of great value to drainage engineers in planning, investigations, and design of interceptor drains. The authors propose a method for determining the flow into a drain and shape of drawdown curve. Where the interceptor drain is installed, near the source of underground water, such as a canal or reservoir, the quantity of seepage may be increased greatly by the proximity of the drain.

The study should, however, be applied to field problems with care. The study assumes that there will be no accretion of water to the flow passing beneath the interceptor drain, and that there is an impermeable barrier at a relatively shallow depth. In practice, seepage from irrigated field and farm canals will probably be present. In many cases, at least small artesian pressures will exist below an interceptor drain after drainage and there will not be an impermeable barrier.

These problems point up the need for thorough investigations in planning interceptor drains. The authors are to be commended for an excellent piece of research. It is hoped that they will continue this work and simulate other conditions such as application of irrigation water to the area below the drain and existence of artesian flow instead of an impermeable barrier.

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11 "A Design Method for Interceptor Drains in Saturated Heterogeneous Soils," by R. William Nelson. Submitted for publication in Agric. Engr.

12 Drainage Engr., Soil Conservation Service, Washington, D.C.

AQUIFER TESTS IN THE SNAKE RIVER BASALT[a]

Closure by W. C. Walton

W. C. WALTON,[1] M. ASCE.—In his discussion Mr. Maasland questioned the value of pumping tests by stating that pumping tests "are no more than 'spot' measurements." The pumping tests discussed in the paper sampled areas of basalt having diameters of several miles. It would seem to the writer that the 'spot' is rather large. The value of the pumping test in evaluating the occurrence and availability of ground water has been discussed in numerous reports and will not be repeated here.

All data concerning the discharge, drawdown, and general performance over the entire Snake River plain, available at the time of the writing of the report (September 1957) were included in the report. Since that time, additional data have become available largely as the result of pumping tests made by the United States Geological Survey (USGS) in cooperation with the United States Bureau of Reclamation (USBR). It is probable that our knowledge concerning the hydraulic properties of the Snake River basalt has greatly increased over the last three years.

Maasland infers that two paragraphs on page 55 are inconsistent. In the third paragraph from the bottom of page 55, the statement is made that the drawdown in well 6N-31E-12ac 1 (5,450 ft from the pumped well) was in the magnitude of 0.1 ft at the end of the test. A drawdown of 0.1 ft is not insignificant as indicated by Maasland but is appreciable and is in accord with the distance-drawdown graph given in Fig. 5. Fig. 5 was used to determine the area of basalt sampled during the test. Therefore, the paragraph at the bottom of page 55 and the preceding paragraph are consistent.

Maasland is correct in stating that the coefficient of transmissibility has an unknown upper limit. A large lava tube must have an unusually large coefficient of transmissibility.

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[a] September, 1959, by W. C. Walton and J. W. Stewart.

[1] Engr., Ill. State Water Survey, Urbana, Ill. formerly Hydr. Engr., U.S. Geological Survey, Boise, Idaho.

DRAINAGE PROBLEMS IN THE SAN JOAQUIN VALLEY[a]

Discussion by William W. Donnan

WILLIAM W. DONNAN,[1] F. ASCE.—This paper deals with one of the most important water management problems connected with the entire California Water Plan. The State Department of Water Resources is to be commended for the vigor with which they are attacking the problem.

In order for the comprehensive scheme of water distribution and irrigation of new lands to function properly, an adequate system must be provided for drainage.

Of particular interest is the problem of drainage of the Tulare Lake Basin. This is a two million acre-area of valley floor lands comprising the south portion of the Valley. To quote the authors, "For all practical purposes, the Tulare Lake Basin is a closed basin draining into Tulare Lake." The delta of the Kings River cuts off the lower part of the valley from a natural outlet to the San Francisco Bay. To the average layman this problem seems remote and of little consequence. After all, the water levels in much of this area have a history of gradual recession. With underground supplies being depleted, why fret about drainage problems? Where is the danger?

The danger lies in the overall salt balance. Suppose that careful plans are made to provide just enough water. Enough for full development of agriculture, suburban and industrial potentials. Then, no drainage problem would develop. The thing that would develop would be a gradual buildup of salts in the subsoil and in the underground water supply. Within 50 yr, possibly one-fifth of the land would be affected to some degree with saline elements.

It seems almost mandatory that some type of drain device or salt balance mechanism be provided for the Tulare Lake Basin. The writer has long been preoccupied with this problem and is fully cognizant of the difficulty inherent in any solution. In fact, as early as 1953, a Master Drain Plan for the Tulare Lake Basin was proposed after a reconnaisance study of the problem.

At the present time three alternative solutions to the problem are recognized.

One solution would be to provide a gravity trunk drain from Buena Vista Lake north to some convenient point in former Tulare Lake bed. Here pumping stations would be built to lift the water about 50 ft to 70 ft up over the barrier created by the Kings River delta.

A second solution, and one which this writer favors, would be to provide a gravity trunk drain from Buena Vista Lake northward for about 55 miles to a point due west of Delano, Calif. At this point, the trunk drain would angle off

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[a] September, 1959, by William L. Berry and Edward D. Stetson.

[1] Agric. Engr., Western Soil and Water Mgt. Branch, Agric. Research Service, U.S. Dept. of Agric., Pomona, Calif.

toward the northeast, roughly on the 215 ft elevation contour bypassing Tulare Lake bed. Then by circling back northwestward to a point one mile west of Stratford, Calif. this main bypass channel would connect with the Kings River wasteway. The bypass channel to this point could be constructed on a grade of about one-half ft per mile. The construction would be such that the western side of the drain channel would consist of a hugh levee.

The bypass channel would, thus, serve two purposes: (1) Transport drainage flow originating in the area from Buena Vista Lake northward; and (2) act as a flood control levee to protect Tulare Lake bed from periodic flooding by the Tule, Kaweah, Deer, and other Sierra Nevada streams.

From this junction point, with Kings River wasteway, the drain would be constructed on a direct line northwesterly to Whitesbridge. This alignment would cross the Kings River delta and would require a deep cut of about 37 ft at the deepest point at Summit Lake. The most favorable aspect of this proposal would be an all-gravity system from Buena Vista Lake to the San Joaquin River.

A third solution to the problem would be to collect drainage flow at some convenient point in Tulare Lake bed and desalinize the water. This last proposal would require an economical method of desalinization. There are perhaps other equally meritorious solutions to this problem. More than likely, the final design of drainage will embody the best factors from several alternatives. Whatever the solution may be to this problem, it seems safe to assert that careful and exhaustive investigations are being carried on to determine the most feasible drainage program for the valley.

ARTIFICIAL RECHARGE OF GROUND WATER RESERVOIRS IN CALIFORNIA[a]

Discussion by Max Suter

MAX SUTER,[1] F. ASCE.—This discussion deals only with two phases of the paper, namely recharge rates and bibliography.

Recharge Rates.—The amount of recharge has increased greatly, especially since Colorado River water is available. To get this water into the ground, more agricultural land is used in recharge areas with a system that allows rates of infiltration seldom over 4 ft per day. No efforts seem to be made to increase this rate, although success in such an undertaking would allow additional increase in recharge without the use of additional farm land. The paper indicates that the reason for the lack of search for an improved method lies in a satisfaction with the present results and a shortage of understanding of the hydraulic conditions on which recharge is based.

This fact can be recognized from the discussion of the influences affecting infiltration rates. Not considered have been such factors as ground water level below spreading site, the depth of the ground water stream, the slope of the bottom formation of the ground water stream, the ability of the ground above it to absorb the recharge water and to spread it over a larger area, whose extent and volume should be known. These factors are important, as any recharge operation can only continue for a long time and to large amounts when the recharge water has a place to go. And naturally the easier the water can flow from the pit, the higher the rate of recharge.

Recharge is on an area, the wetted area, whereas spreading is on the circumference in linear order, the area increases faster than the circumference and, therefore, for larger areas, the inflow can be greater than the outflow.

Considering these conditions, the Illinois State Water Survey was able to reach recharge rates of 60 ft, 100 ft and even up to 200 ft per day; that is, 15 to 50 times the maximum rates obtained in the California operations. The Peoria operation has been fully described elsewhere.[2,3]

Bibliography.—Ordinarily the bibliography gives data concerning works cited in the text or lists the main works containing additional important information. Neither of these two cases is applicable to the bibliography attached to the paper. There is not a single reference to any publication in the text. The grade of importance of the papers listed will not be judged here, but it is remarked that the list is incomplete relative to some very important papers.

Completeness of a bibliography probably can never be attained, even if only American literature is listed. If foreign literature is included, (and in

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[a] December, 1959, by Raymond C. Richter and Robert Y. D. Chun.

[1] San Clemente, Calif.

[2] ASCE Proceedings Paper 1102, November, 1956.

[3] J.A.WWA, Vol. 48, p. 355, April, 1956.

scientific references this should always be the case), completeness is more difficult, even if limitations are placed on date and content. With clear definitions, the latter may still be subject to personal judgment and thereby be out of a "satisfying everybody" class.

However, mistakes should be avoided, and this includes listing of unpublished reports (10,13), only title of publication, no author, no source or date (27,28), paper in preparation (16), duplications, (56-59), or plain office reports of local distribution; about 8 references belong in the latter group.

Actually, a general bibliography would have been more easily obtained if reference had been made to Todd, No. 66, (since published as Water Supply Paper 1477) and a list had been given of papers before the end of 1954, but missing in Todd's annotated bibliography and, also if a fairly complete list of publications since 1955 had been supplied. This would be a service.

May it be added that the whole question of references and bibliographies, and the question of what to include and how to list and quote, merits some special study and a apper open to discussion.

THIS PROBLEM OF WATER RIGHTS[a]

Discussion by Robert O. Thomas

ROBERT O. THOMAS,[1] F. ASCE.—The basic constitutional question of due process, as it pertains to compensation for property, requires an examination into the nature and attributes of the property in question. The riparian right is a characteristic of property abutting a stream. Although certain lands may, in accordance with the principles of riparian law as applied by the courts, be deprived of riparian rights that were previously part and parcel of the property, the right itself cannot be sold separately and apart from the real estate to which it pertains. The courts of most states have, generally, adhered to the position that the riparian right pertains only to the smallest tract of land, abutting upon a stream, that has been held in a continuous chain of title. Thus, as non-abutting portions of the realty are disposed of by various owners, the sundered portions lose the riparian characteristic unless it is specifically reserved to such parcels in the deed of transfer. Once having been lost, a parcel may not regain the riparian right by being joined with an abutting parcel by a subsequent owner.

There are, it is true, a few cases wherein it has been held that an owner of abutting property may, by the purchase of adjoining nonriparian parcels, again confer upon those parcels a riparian status. However, such cases are exceptions, and are not generally applied as precedents. It appears, therefore, that as land becomes more intensively developed, sales and exchanges of real estate will probably have a cumulative effect in reducing the acreage of land that enjoys a riparian status. This will, of course, reduce the annual demand of such lands upon the available water supply.

The riparian right, however, is not solely a right to the use of water, but, also, has been held to constitute a right to have the water flow by the property undiminished in quantity and unimpaired in quality. This aspect of the riparian right has nothing to do with any use of the water by the riparian proprietor, and may be likened, in the words of the United States Supreme Court, to the status of "res communes—that is, things common to all and the property of none." This aspect probably derives, in its antiquated sense, from the original use of rivers and streams as one of the major means of transportation of both persons and things. Today, except for our principal waterways, value of this riparian aspect probably lies in the aesthetic or recreational value of the watercourse.

There could exist the increased probability of a continually diminishing use, based upon the riparian right, and a recognition on the part of water resource development planning agencies of the desirability of recreational use

[a] December, 1959, by Robert L. Smith.
[1] Sacramento, Calif.

and fish and wildlife maintenance in our stream courses. In such a case, and bearing in mind the riparian rights, the objections to water rights legislation could be readily reconciled with the desirable objective of providing ample water supplies for the beneficial uses required by the economy. Those who advocate the absolute and unvoidable supremacy of riparian water rights as an element of determinable value, over and above the valuation of the land to which the right is appurtenant, should consider the possibility that such valuation would be accepted by assessing agencies as a basis for increasing the taxable obligation of the property concerned.

A basic tenet of statutory appropriation legislation is that each succeeding right may only be exercised after all senior rights have been satisfied in full and pertains only to waters surplus to such prior rights. Since the riparian right is inherent in a piece of property by virtue of its location abutting a watercourse, it does not depend upon whether or not actual use of water is made under claim of that right. Therefore, if water right legislation is adopted in any state presently recognizing the common law status of riparian rights, all such rights are co-equal in status and their priority will antedate any system granting appropriative rights. Appropriative rights could only be initiated subsequent to the passage of permissive legislation and, hence, would be junior to riparian claims.

While the law constitutes a balancing force against change in the relative rights and obligations of individuals that is too rapid, it does evolve reasonably and logically in accordance with the progress of civilization. Innumerable instances of this can be pointed out. It is not so long ago that the law jealously guarded the right of the individual to hold other human beings in the bondage of slavery and, in the same regard, it permitted the labor of young children to be sold and bartered. Property owners were protected in whatever use they desired to make of their property, whether or not such use was obnoxious to their neighbors. Now, however, slavery has been abolished in this country and the validity of zoning laws, child labor laws, minimum wage laws, and many other laws pertaining to the general welfare is recognized.

There is, therefore, no apparent reason why men of good will cannot formulate equitable legislation and agreements, recognizing and protecting the riparian rights in our water-courses, while at the same time providing for the conservation and salvage of much of the precious water supply now wasted to the oceans. It can be shown that the riparian proprietor often receives benefits from the development of the waters of a stream system, for which he makes no corresponding payment, while, at the same time, he retains all of the rights he previously had to the use of the waters in the stream.

The value of water conservation lies in the ability, and capability, to store excess high flows, that usually occur annually on most streams. These flows add little, if anything, to the attractiveness of the stream for the riparian proprietor. In fact, they may actually prove damaging to his lands since, if high enough, they may flood a considerable portion of his property, thereby causing excessive damage. Such flood waters, however, stored for annual or carry-over cyclic use would, under the laws providing for the appropriation of surplus waters, provide a great benefit to the general economy of the state or nation. The appropriated waters could either be taken from the storage reservoir and transported to the place of use by an independent conduit system, or could be released and permitted to traverse the water-course to a

point adjacent to their proposed place of use. In either event, the water actually and reasonably needed by riparian proprietors would always be available in the watercourse. In fact, under proper planning and operating concepts, additional water released for recreational purposes or for the maintenance of fish and wildlife would also be present in the stream.

While different uses or functions of the water supply might sometimes be separate and sometimes combined, no distinction could be made in the stream itself between the use of one drop of water and the use and purpose of another. Ample opportunity would remain for riparian proprietors to take from the stream that to which they were entitled. In this connection it should be borne in mind that since all riparian lands must, by definition, be within the watershed of the stream to which they are riparian, it matters little how much the riparian proprietor, in the ordinary course of events, diverts from the stream, since the land has a determinable capacity to use the water, and all unused water will return to, and augment, the stream within or adjacent to the place of taking.

With these considerations borne in mind, and with the subject of riparian rights and riparian proprietorship of land removed from the realm of emotion and arbitrary decision, it is possible to evolve systems of statutory water law covering the entire spectrum of water rights, water uses, and water development as a combined objective for the general welfare. This should be the ultimate objective of all proposals for the administrative regulation in those states not presently controlling this valuable and irreplaceable resource.

LEGAL ASPECTS OF GROUND-WATER UTILIZATION[a]

Discussion by Raphael G. Kazmann, Frederick L. Hotes, and Paul Baumann

RAPHAEL G. KAZMANN,[1] F. ASCE.—The author has done an outstanding job in bringing together a discussion of legal principles in view of hydrogeologic fact. The author's criticisms of the University of Michigan's "Model Law" are well founded and the writer would like to enlarge upon them.

"(b) Existing riparian uses are confirmed, but those which have never been exercised are disallowed."

The principal difficulty with riparian doctrine is that no one can count on using water. By "using" is meant either to evaporate it or to degrade it in quality—as by heating it, or increasing its minieralization or organic content. The sanctioned riparian "uses" have less effect upon the flow of a stream than do the natural variations of evaporation and rainfall. Modern industrial and agricultural practice, however, alters or consumes water. It seems to the writer that the whole basis of operation of the economy, including its expansion, requires a sound legal framework for the acquisition of a property right in the use of water. This property right could be sold, transferred, or condemned in the same manner as any other property right. Appropriation doctrine is the only tested basis for water resources investments since it gives assurance that water will be available for beneficial use insofar as nature permits, without consideration of the changing definition of "beneficial" put forward by some bureaucratic authority. Long range investments in water using facilities are, therefore, justified. And this brings us to:

"(c) Except for existing uses of water, which are unlimited in duration, fifty years is the maximum terms for which a right of water use may be secured."

In the writer's opinion there is nothing more calculated to promote confusion and uncertainty as regards the allocation and utilization of water resources than this arbitrary restriction, now embodied in the "Model Law," that actually seems to constitute a new sort of property right. We can readily visualize the periodic reopening of old rivalries and the constant off-season political struggle, as the control of water resources periodically "comes up for grabs" by public organizations, individuals, governmental bureaus, and corporations. This built-in reopener clause is a pernicious provision which will not serve to develop the beneficial use of water but will serve to promote

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[a] December, 1959, by Robert O. Thomas.
[1] Cons. Engr., Stuttgart, Ark.

turmoil. A water right should be in the same category as ownership of land or other property.

These comments, of course, reinforce the author's criticisims (d), (e), (f), and (g). As Mr. Thomas points out, the omission of a provision for the conjunctive use of ground and surface water supplies is a serious lack.

In general, it has always seemed strange to the writer that the University of Michigan, located in a state lacking in the experience of water law, should feel called upon to draft a "Model Law"—not just a law applicable to Michigan—whereas law schools located in states having from 20 yr to 50 yr of experience in the operation of water legislation are far more hesitant in this regard.

An intensive study of the publication issued by the University of Michigan Law School, entitled, "Water Resources and the Law," indicates to the writer that the objective of their "model water law" is to give to an administrator complete power over the use of water by anyone, organization or person, on the basis of "beneficial" use, with the administrator defining what he means by "beneficial" at any particular time. Thus, the "Model Act" discards predetermined external standards. This proposed grant of arbitrary power is both undesirable and dangerous.

All existing water-use legislation can be characterized as being "water oriented." This means that the underlying assumption is made that the beneficial utilization of the water substance itself is the only matter to be considered. By no means should this assumption go unchallenged. Actually, in many instances the most beneficial use of water is to get rid of it. This is true to some extent in the production of every kind of mineral—the dewatering of ore bodies is an essential part of the mining process. It is well to remember that our modern civilization rests upon an ever-broader base of mineral utilization and upon the commercial development of ever-leaner rocks and ores. This means that the disposal of water from the workings can be expected to be a problem of increasing importance.

To the knowledge of the writer, the "beneficial" waste of water has not been provided for in any water-use legislation. The "corpus" of the water, under existing legislation, must in itself be utilized.

Under the doctrine of appropriation, there is always the possibility that the state engineer, or other proper authority, may be able to declare that the disposal of water from mines or excavations is a beneficial "use" of the water. Even so, it is not at all apparent on what basis the seasonal variations in ground-water flow, or the increases in ground-water flow due to extension of the mine workings, are to be handled.

In states where the riparian doctrine, or some possible modification of it, is more or less in force, the status of ground-water developments, as well as mine dewatering, is unclear. The "model" law never comes to grip with the issue of the beneficial waste of water. The author, in his closure, is invited to propose a method for handling the problem of "beneficial waste" by legislation.

In essence, therefore, the writer subscribes to the tenor of Mr. Thomas' remarks on the legal aspects of ground-water utilization. It is the writer's opinion that the "model" law, as it is now proposed, is a pernicious piece of legal draftsmanship that is totally unprincipled in that it gives to unknown officials the absolute and arbitrary right to declare who shall use water and

when. The officials can do this in the name of the "public good" by declaring that one use of water is "beneficial" as compared to another.

The real problem is to extend the operation of our present system of property rights to the field of water utilization and, thus, bring water more efficiently into the process of production, not to grant arbitrary powers of life and death to faceless administrators in the name of the public welfare. Mr. Thomas has done the profession and the country a service by expressing the real problems in the field of water development clearly and adequately.

FREDERICK L. HOTES,[2] F. ASCE.—An excellent summary of a voluminous topic has been presented by the author. Most important, he has focused attention on some of the significant problems that today face the engineer who plays a prominent role in the conservation and development of the ground waters of the United States. These problems, however, are not within the exclusive province of the engineer. They belong also to the geologist, the lawyer, the jurist, the public official, the economist, and above all, to the man on the land who uses these waters to gain his livelihood.

Recognizing the broad cross-section of life that is concerned with ground water problems, the writer wonders if the author is not being unduly harsh with the legal profession when he implies that many of their decisions "have often served only to complicate the use and development of ground water." Certainly the basic intent of any judicial decision is to clarify, not to confuse, although it is recognized that this objective is not always obtained. The fact that legal provisions and decisions are often complicated is due perhaps more to the inherent complexity of ground water hydrology, rather than to any other cause. Often the jurist must resolve conflicting expert testimony on technical matters; because those who should be best qualified to determine and interpret the facts, cannot themselves agree. There will never be a ground water code that can adequately cover all possible circumstances. Interpretations and judgment, on the part of engineers as well as others, will always be required. Improvements in water law and regulations, however, will continue to accrue, as in the past, from the joint efforts of engineers, scientists, lawyers, and laymen, to enlarge knowledge and understanding of both technical and nontechnical aspects of the field.

Complex water law is not solely the affliction of the highly-developed civilization of the western United States. The writer has had experience in the Middle East with equally complex customs, traditions, and laws governing the use of surface and ground waters. Irrigation has been a vital portion of the life of this region since long before the time of the Roman Empire. Here, water is used in accordance with tribal, religious and governmental law, written and unwritten, developed over centuries. Whereas details of the law differ even more widely over that area than within the United States, and practically none of it is codified, the basic elements of our riparian and appropriation doctrines can be readily identified everywhere. Wherever the irrigation engineer works he finds a knowledge of local water law necessary for the formulation of practical development plans. Hence, the appropriateness of papers such as the one under discussion, to appear at times in the technical journals of the Society.

[2] Chf., Div. of Land and Water Resources Development, Engrg.-Science, Inc., Oakland, Calif.

In his discussion of the Model Water Use Act, the author under item (d) mentions a possible priority list of beneficial uses. The writer agrees that this should not be an administrative prerogative, but believes that for the most important uses it is a necessary legislative prerogative and duty. California law clearly establishes two relative priorities; domestic being the highest use, and irrigation being the next highest use. Nothing is stated concerning industrial use, one of the significant beneficial uses. There are indications that the term "municipal use" has been considered as a type of domestic use, even though industrial water demand may be as much as one-third of the total municipal demand. With economic competition for water increasing, the question arises as to the relative priority of industrial and irrigation uses.

If an industry were to appropriate water in its own name, its priority of use, in case of water shortage, or for the granting of a new right, would be less than that of an irrigation use. If, on the other hand, a municipality were to secure the right to the water, and in turn supply it to the industry, the same physical use of the water would have precedence over irrigation use, thus reversing the apparently stated priority of irrigation over industrial water use. To the writer's knowledge, this issue has never yet been brought before a court of law. Is it proper to interpret the foregoing to mean that the industrial use of water within a municipality is as vital to the life of the city as its domestic use, but that industrial use not derived from a municipal supply is not as important? Legislative definition and clarification may be required ultimately.

The author raises the question as to what ground water appropriators in New Mexico can do after exhausting their water supply. There are three alternatives open to them, namely,

1. Import supplemental water. This may be uneconomic.
2. Reduce draft to safe yield. This will automatically occur once the basin is depleted.
3. Sell-out, and let someone else worry about the application of alternatives one and two.

The author has ended his article with the strong implication that ground water operations will be subjected more and more to administrative and executive, as well as judicial, control by State governments. There are alternatives, such as local governmental units and water user associations, but these may not be able to provide the legal, financial, and technical effort required to match the problems of the future. Even more important, they may not be willing to do so, although theoretically able to do so. Such being the case, the Progress of the Commonwealth will generally proceed by the best available remaining course. Where the State Government also is unwilling or unable to act, then the Federal Government may be the next logical alternative. Examples of all types exist today. It will be interesting to observe the trend of the immediate future.

PAUL BAUMANN,[3] F. ASCE.—Mr. Thomas is to be complimented upon his review of the water right evolution, in general, extending over the past century, and the more recent legal aspects of ground water utilization, in particular.

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[3] Cons. Engr., formerly Asst. Chf. Engr., Los Angeles County Flood Control Dist.

Successful enactment, in 1958, by the California Legislature, of statutes authorizing the formation of (ground water) Replenishment Districts should, above all, be credited to the foresight, initiative, and leadership of the West and Central Basins Water Associations, in Los Angeles County. These associations, and particularly the former, were, likewise, instrumental in the enactment, in 1951, of an amendment to the Los Angeles County Flood Control District Act, (originally created by the California Legislature in June, 1916) which authorized said District to establish water conservation Zones. Subsequently, two of such Zones were established, Zone I, generally overlying the Central Coastal ground water basin, and Zone II, the boundaries of which generally coincide with the boundaries of the West Coast ground water basin. In brief the purpose of these Zones was to produce a revenue through taxation, limited to five cents per hundred dollars assessed valuation with which the Flood Control District could purchase water from outside sources to be conserved through spreading or other means within the revenue producing Zone.

Prior to this amendment the act provided for the conservation, but not the purchase, of waters by the Flood Control District. Hence, the Zones were a forerunner of the Replenishment Districts, one of which comprising both West Coast and Central Coastal Basins, was formed in 1959.

Through a fine distinction in the wording of the Zone versus the Replenishment District provisions the respective boundaries could be at variance. Within the boundary of the Zone all land was to be included which was specially benefitted through extractions of water from the ground water basin, whereas within the boundary of the Replenishment District all land thereby benefitted was to be included. The legal interpretation of "special benefit" was the predominant (more than 50%) use of extracted ground water.

In a constructive manner, the author sets forth legislation necessary to supplement current provisions or practices in ground water utilization in light of available basin storage and recharge. To the writer's knowledge, little difficulty has so far been encountered on the part of owners of land overlying a ground water basin in putting water extracted therefrom to use on his land even if such use could not be considered strictly beneficial. However, the same owner of land is likely to take exception if his neighbor should extract ground water for use not on overlying land even if such use happened to be strictly beneficial, such as domestic use. Recent litigation in the southern part of the state of California was a case in point.

A water company with large holdings overlying a ground water basin had been extracting and exporting ground water for domestic use. Farmers overlying the same basin had been extracting ground water for irrigation and other agricultural use on their land. All was well until the current drought started, in around 1943, and with it the depletion of the ground water supply began, which depended principally upon stream flow percolation besides rainfall on the area itself.

Like many southwestern streams, the one in question would produce occasional flash floods and little if any flow in between. Although such flash floods became fewer and farther apart as the drought progressed, a considerable volume of potable water would waste to the ocean due to lack of absorption capacity of the streambed. Hence, the depletion of the basin continued and the case was taken to court. Here a number of ideas were propounded in regard to ground water rights which in light of the author's outlines and suggestions are believed to be worthy of mention. They bring out the fact that ground water rights are still vague and indefinite.

The water company offered to construct spreading grounds capable of conserving most of the stream flow which would otherwise waste to the ocean and to substantially limit its exporatation of ground water to the quantity so conserved. The spreading grounds would be located on company property.

The opposition countered that although spreading were performed on company property, the water so conserved would not necessarily be stored exactly underneath said property and that the company had no right to store it anywhere else. Furthermore, in extracting water from the basin the company had no right to extract any water, except particle by particle the very same water it had conserved.

While on the face of it these arguments sound far fetched if not harebrained, they nevertheless cannot be denied the claim of being food for thought.

AMERICAN SOCIETY OF CIVIL ENGINEERS

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 2270 is identified as 2270(ST9) which indicates that the paper is contained in the ninth issue of the Journal of the Structural Division during 1959.

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c. Discussion of several papers, grouped by divisions.

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PART 2

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NEWS OF THE IRRIGATION AND DRAINAGE DIVISION OF ASCE

JOURNAL OF THE IRRIGATION AND DRAINAGE DIVISION
PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

DIVISION ACTIVITIES

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IRRIGATION AND DRAINAGE DIVISION

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CALENDAR OF COMING MEETINGS

June 20-24, 1960. National Convention, ASCE, Reno, Nevada. The Irrigation and Drainage Division will sponsor four half-day sessions at this convention and will be co-sponsor with the City Planning Division of an additional session. Ken A. Christenson and P. H. McGaughey will be session chairman for the two sessions on "De-salinization of Water," Arthur E.

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Bruington will be session chairman for a session on "Conservation of Water," and Kenneth Q. Volk will be chairman for a session dealing with four topics of local interest. The entire I&D Division program for this convention has been arranged by our committee on Session Programs with the active local cooperation of Ken Volk, Division Vice-Chairman.

August 17-19, 1960. Annual Conference, Hydraulics Division, ASCE University of Washington, Seattle, Wash.

August 28-31, 1960. Annual Convention, Soil Conservation Society of American, Ontario Agricultural College, Guelph, Ontario, Canada.

September 29-30, 1960. Nevada Water Conference, Carson City, Nevada.

October 10-14, 1960. National Convention, ASCE. Hotel Statler, Boston, Mass. No Irrigation and Drainage Division sessions.

November 16-18, 1960. National Reclamation Association, Bakersfield Inn, Bakersfield, Calif.

April 10-14, 1961. National Convention, ASCE, Phoenix, Ariz. The Irrigation and Drainage Division plans to sponsor four half-day sessions on the theme, "Water Conservation in Arid Areas." These sessions will constitute the Irrigation and Drainage Division technical conference for 1961. A number of papers already have been proposed for this convention, and any further suggestions for papers should be sent to Dean Christensen, Chairman of the Committee on Session Programs or H. E. Prater, Vice-Chairman.

October 16-20, 1961. National Convention, ASCE, New York.

In the future: The Irrigation and Drainage Division also plans to sponsor technical sessions at the Houston Convention, in February, 1962, the Omaha Convention in May 1962 and the Detroit Convention in October 1962. Send your suggestions for subjects to be discussed at these meetings to Herbert Prater, Vice-Chairman of the Committee on Session Programs.

The Division executive committee is scheduled to meet in Reno during the week of the National Convention. Division members are invited to contact the executive committee members with suggestions regarding future convention and conference programs. This also would be an excellent time to volunteer your services on one of the division's many technical or administrative committees, as a speaker on a future program, or as author of a paper for publication in the I&D Journal.

RESEARCH COMMITTEE

Santa Fe, N. M., was the location for a meeting of the division Research Committee on January 8 and 9, 1960. Committee Chairman G. B. Keesee presided and committee members Albertson, Blaney and Hardman were present. John H. Bliss, Chairman of the Executive Committee, attended during most of the 2-day meeting. Welcome visitors and observers included Lloyd Nicholson, Area General Engineer, Bureau of Indian Affairs, from Gallup, N. M., and Morris Skinner, Research Engineer, Colorado State University, Ft. Collins, Colo.

Final plans were made for the New Orleans Convention session on research, and planning was started on research sessions for the Phoenix and Houston conventions of the society.

The next meeting of the Research Committee is scheduled to be concurrent with the first fiscal year 1961 meeting of the division Executive Committee. At that time the program for the Phoenix convention will be finalized. Contact Chairman Keesee or one of the committee members with your suggestions for future programs sponsored by the Research Committee.

IRRIGATION AND DRAINAGE PRACTICES IN HUMID AREAS

The April issue of Civil Engineering carried a complete and quite complimentary report on the New Orleans convention sessions which were sponsored by the Committee on Irrigation and Drainage Practices in Humid Areas. With more than three million irrigated acres in the 31 eastern states and blocks of 500,000 acres or more in several of them, irrigation must be considered a national activity of ASCE. This committee met in New Orleans during the convention week specifically for the purpose of planning a manual on irrigation and drainage in humid areas. The manual, as presently visualized, will consist of an introduction and 14 chapters, 7 each on irrigation and drainage. Individual chapters have been assigned to members of the committee and a schedule of target dates for submission of material to the committee was adopted. Committee members assigned particular subjects are expected to review previously published information on these subjects and select the most worthwhile for incorporation into the manual or listing in a bibliography.

A tentative outline of the proposed manual is as follows:

INTRODUCTION

Potentialities of Irrigation and Drainage in Humid Areas

IRRIGATION

I Inventory of Natural Resources

II Lands Suitable for Irrigation

III Methods of Irrigation

IV Economics of Irrigation

V Construction Problems and Costs

VI Legal Problems

VII Facilitating Services

DRAINAGE

I Flood Control

II Drainage of Irrigation Waste

III Subsurface Drainage of Seeped Land

IV Cross Drainage for Canal Structures

V Control of Phreatophytes

VI Economics of Drainage

VII Legal Problems

UNIVERSITY OF CALIFORNIA WATER RESOURCES CENTER

From University of California Prof. J. W. Johnson, F. ASCE, comes word that the Water Resources Center Archives is gathering materials and data in the water resources field. The collection will include all aspects of water: water as a natural resource and its utilization; irrigation; flood control; municipal and industrial water uses and problems; water rights; and water development projects. The emphasis is on material relating to the State of California.

Besides actually acquiring material, the Archives is interested in locating and making biographical listings of important collections which remain in public or private agencies and in engineering offices. A comprehensive catalog will thus be developed for the use of researchers, describing and giving the location of existing unique hydrologic data in the State.

Because the materials found to be the most valuable are not available in the sense that they can be purchased such as most libraries purchase books, the Archives relies upon the cooperation of interested individuals and agencies for augmenting its collection. Engineers' reports and studies (unpublished materials, manuscripts, etc.), agency reports, pamphlets, hearings, legislation, specifications, maps, scrapbooks, newspaper clippings, speeches, campaign material, and books pertaining to water: all are being sought. Interests include both current materials and the historical aspects.

The entire collections of several men prominent in the water resources engineering fields are now housed in the Archives: among these important gift collections are those of Frank Adams, Bernard A. Etcheverry, Charles Gilman Hyde and Baldwin M. Woods.

Seven reports have been prepared and published by the Archives, all of them available to the interested public:

1. The Etcheverry Collection in Water Resources Archives (June, 1958).
2. Theses on Engineering, Economic, Social and Legal Aspects of Water (Oct. 1958).
3. Watershed Management Research Data, U. S. Department of Agriculture, Forest Service, California Forest and Range Experiment Station, Berkeley and Glendora, California (Feb. 1959).
4. Publications and Reports of Charles Gilman Hyde (July, 1959).
5. Water Pollution data, Regional Water Pollution Control Boards, State of California (July 1959).
6. Bachelor of Science Thesis on Water Resources Engineering, University of California, Berkeley (Aug. 1959).
7. Theses on Water Resources, Stanford University, California Institute of Technology, and University of Southern California (Aug. 1959).

Agencies dealing with water in any of its forms or uses are requested to add the Archives to their mailing lists. Person having materials which have served their purposes are urged to consider the Archives a repository for the filing of these materials.

The Archives serves researchers in the University community as well as the interested public. The activity is under the direction of Professor Johnson, Director of Hydraulic Laboratories, University of California, Berkeley. Gerald J. Giefer is the Librarian directly in charge of the Archives.

The mailing address of the Archives is: Water Resources Center Archives, Room 5, Mechanics Building, University of California, Berkeley 4, California.

ASAE PUBLISHES TRANSACTIONS

The American Society of Agricultural Engineers recently published Vol. 3, No. 1 of its Transactions, this being a Special Soil and Water Edition. It includes 33 papers dealing with water quality, consumptive use, land preparation, water conveyance and application, and other subjects of interest to irrigation and drainage engineers. ASCE members represented among the authors include: Edward R. Bauman, M. M. Culp, Vaughn E. Hansen, Orson W. Israelsen, John L. Merriam, Harold O. Ogrosky, Dean F. Peterson, Harold C. Schwalen, Carl R. Wilder and Lyman S. Willardson. Copies of this edition of ASAE Transactions may be obtained from ASAE headquarters, 420 Main St., St. Joseph, Mich., at $4 per copy.

COLORADO IRRIGATION AND DRAINAGE DIVISION ACTIVITIES

The April 27 meeting of this group heard a talk on "Groundwater in Colorado." The speaker was E. A. Moulder, District Engineer (Groundwater), U. S. Geological Survey. Nearly one million acres in Colorado are irrigated with water pumped from the under-ground reservoirs. A major problem of the state is to formulate and adopt policies which will assure the conservation and beneficial use of these tremendously valuable resources.

The May 25 meeting, under the sponsorship of the Colorado Section's Hydraulics Division, will present a talk by Paul D. Doubt, M.ASCE, on the use of electronic computers for the solution of water surface profiles. Mr. Doubt is Head, Reservoir Section, Engineering Division, Soil Conservation Service, Beltsville, Md.

Election of officers for 1960-61 will take place at the May meeting. The following have been nominated:

Chairman: Walter C. Ohlsen, U. S. Bureau of Reclamation
Vice-Chairman: Fred A. Houck, Engineering Consultants, Inc.
Sec'y-Treas.: Ronald K. Blatchley, Tipton & Kalmbach, Inc.

Floyd E. Dominey, Commissioner of the U. S. Bureau of Reclamation, recently told members of the Oklahoma Reclamation Association something about the economics of irrigation in south-western Oklahoma. He referred to the 40,000-acre irrigated crop area served by the Lugert-Altus Irrigation District. Irrigated farms of this district produced an average crop return in 1958 of about $160 per harvested acre, which is well above the returns from nearby dry-farm operations. Since irrigation in this district started about 1946, these farms have produced crops worth about $50 million, two-thirds of which is new production, over and above what would have been realized without irrigation. Based on studies on a similar irrigated area, the Bureau of Reclamation estimates that each increase of $1 in crop production creates

an additional $1.10 in local labor income. This in turn creates $1.50 worth of increased labor income in the regional trade area. Thus the increased production of $33 million created by this project has created $36 million in local labor income and $50 million in regional labor income since 1946.

No doubt many similar and perhaps more outstanding examples of irrigation benefits could be cited. Irrigation engineers should be aware of all the benefits resulting from their activities, as well as their engineering aspects.